

Highway Traffic Estimation

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THE ENO FOUNDATION FOR HIGHWAY TRAFFIC CONTROL
SAUGATUCK • 1956 • CONNECTICUT

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FOREWORD

In preparing this report, the Eno Foundation is aware of two facts: first, that we have hardly crossed the threshold of knowledge relating to traffic movement and motivation; second, that information relating to traffic estimating is widely scattered and resident in empiricism and judgment.

With the rational method still a developing technology, it seems worth while to solicit pertinent information on the subject from available sources and compile it for such analysis and conclusions as it might afford. It is recognized that formulas cannot always substitute for judgment in the planning field, and that some concepts must be expressed in principles rather than in mathematical precision.

The preface to this volume contains the authors' acknowledgments. The Eno Foundation wishes to add its grateful appreciation to the many individuals and agencies that pooled their information and gave generously of their counsel. Their donations are the basis of the report.

It is the Foundation's hope that the book will stimulate further research in this subject of growing importance. It will be through research into traffic movements—its motivations and its effects—that a more efficient relation between land use and traffic artery can be determined.

The Foundation is aware that the authors worked diligently with an understandable and constructive approach toward the accomplishment of their difficult objective.

ENO FOUNDATION

Saugatuck, Conn.

PREFACE

This publication is intended as a guide for highway planning, design and traffic engineers, and for others who must anticipate traffic requirements or predict the effects of changes made in traffic facilities.

It is concerned primarily with three aspects of traffic estimating: first, the traffic generating characteristics of major urban land areas; second, the relative attractiveness of various types of routes serving traffic between zones of origin and destination; third, the growth of traffic resulting from increases in population, vehicle ownership, vehicle use and other factors.

Appraisals of specific facilities are related to their environments in terms of significant economic and sociological data.

The subject matter constitutes one of the elements of planning technology which has been only partially explored and in which common practice has not been established. Notwithstanding, day-to-day decisions must be made in planning, designing and operating highway facilities. Since such decisions reflect the knowledge from which they derive, it is deemed worth while to inventory and disseminate current information.

The authors acknowledge with full appreciation the contributions of those furnishing data for use in this report. Their aid and advice, stimulating and essential, contributed materially to its completion. Credit for specific data and ideas is given in the footnotes.

M.E.C.

R.E.S.

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CHAPTER ONE

INTRODUCTION

Over the centuries, land travel has evolved from foot to wheel to self-propelled vehicle. With each advance in mode, there has ensued a dramatic revolution in distance, time, and travel pattern.

Within memory there was a period of relatively little travel as compared to the motor vehicle age. Man lived a quiet life in the neighborhood of his birth, enjoying more of friendship than of travel and fame. Rarely did he travel far.

With the motor vehicle came a system of improved roads. The accompanying mobility extended the opportunity and orbit of travel. Though the average trip length now does not exceed fifteen miles, the frequency of both long and short trips has greatly increased.

Mode of travel influenced the habitat of man—from nomad to urbanite to suburbanite. The motor vehicle has made it possible for man to satisfy an innate desire: to live where he may enjoy the land and yet retain the special cultural and commercial benefits of the city.

Man has many motivations for travel. His gregarious instinct, his inherent curiosity, his socio-economic requirements, and many other tangible and intangible, physical and psychological factors combine to provide motivating influences—to push and to pull, and to put him on the go. At the same time various kinds of vehicles and facilities have abetted or impeded man's movement.

For the greatest movement, maximum motivation must be matched with maximum mobility. The least movement results when either or both of motivation and mobility is lacking. Too little is known of the relations of motivation, mobility and movement.

In the early planning of our cities, the fingers of two types of planners are discernible: the profit-minded land-owner, and the bold, esthetic planner. The first had little regard for service or

beauty, and the second emphasized beauty at the expense of service. In those days the service function had not been recognized as an important one. Few planners knew the service demands nor would they have known how to translate traffic values into design values.

The highway and street planner of today appreciates keenly the importance of the *service* function of the traffic way. While he seeks to provide avenues that will grace their surroundings, he attempts at the same time to provide adequately for the service function. Today the planner estimates the service demand and translates this into a location and design that will provide the greatest benefits to the most people, fitting the new facility effectively and pleasingly to the existing highway system and the topography.

Need for Traffic Estimation Urgent

The concept of functional design suggests the need for traffic estimation. The urgency is perceived when one is apprized of the need for spending billions of dollars for new highways and streets. It is personalized when one travels present inadequate and heavily congested arteries. It is brought into bolder relief when one is aware that a great unserved potential traffic exists. There is an insufficiency of routes and terminals, and it has long been recognized that a new facility not only responds to the existing traffic demand but releases unserved potential. The urgency is further accentuated by the expected growth of traffic. The motor vehicle has gone far to provide mobility, but until there is a sufficiency of adequately designed highways and streets, the optimum in traffic movement and its influences cannot be attained.

Estimates can be made of vehicle registration and vehicle mileage for the year ahead. Unless substantial changes occur in factors affecting vehicular travel, these estimates will probably approach the true value. Estimating travel for an individual vehicle is not as simple, because there are few, if any, "average motor vehicles," and individual cars cannot be indentified as average cars. Estimation is concerned with the determination of normal

patterns in diverse places, the limits or ranges, and their correlations with the major causal factors and conditions of travel.

Experience taught us to be cognizant of the need for firm bases for traffic estimation.

Though new facilities have been built in the form of expressways, turnpikes and bridges, there has been no generally accepted method of estimating their use, whether by diversion from existing routes, conversion from other modes of travel, or in the amount of new traffic that will be induced.

An effort has been made to draw together as much as possible of the knowledge of valid methods of estimating. Information was sought from state highway departments, traffic engineers, consultants and other agencies and individuals having a knowledge of the subject.

This report is a digest of the information received. It is an effort to remove some of the conjecture and guesswork from the techniques of traffic estimating, to lend experience to judgment, and principle to speculation.

An analysis has been made of research undertaken to identify factors and conditions affecting traffic flow and to measure their effect on volume and direction. Comparative analyses of origin and destination surveys have been rewarding in showing the relation between land use and travel patterns. Diversion studies affirm the "least energy concept" of traffic movement; continuous volume counts assure the stability of patterns and trends.

Prime factors affecting traffic movement include trip purpose, opportunity, length of trip, freedom of movement, and economic level of vehicle owner. Other factors contribute to influence the magnitude or frequency, direction, and distance. Some, such as age and sex, may be important where there is a substantial deviation from the norm.

It has long been obvious that traffic terms have been variously used and interpreted. Where quotations are used, original terms are preserved as their meaning will be clear from the context. The authors offer definitions to clarify their usage of various old and new terms. A nomenclature that would be universally accepted should be devised.

Terminology

1. **Diverted Traffic:** A component of traffic which has changed from its previous path of travel to another route without a change in origin, destination, or mode of travel.

Example: A part of the normal daily travel pattern in a city may consist of traffic between a suburban residential area and an industrial area. This traffic may normally use a major street route from origin to destination. If a new expressway is built roughly paralleling the major street, a portion of the daily traffic volume will be diverted from the major street to the expressway because of savings in time or distance, increased comfort or convenience, or other advantages to the drivers.

2. **Converted Traffic:** A component of the normal traffic pattern which has made a change in its usual mode of travel.

Example: In the situation described in (1) above, the improved route between origin and destination may convert some workers who formerly used mass transit to the use of their private automobiles for daily commuting.

Conversely, increased street congestion and lack of parking facilities may tend to convert auto drivers into mass transit users.

3. **Potential Traffic:** The total volume of traffic that would in all probability move between two terminals (or on a given route), assuming ideal transmission facilities.

Example: Based on such factors as population, type of land use, economic conditions, human needs, and others, there is a theoretical maximum volume of trips which might be made between any selected origin and destination. The theoretical maximum travel will probably never be attained, because of the frictions of time, distance, and cost.

The term "potential traffic" is offered as a convenient label to be applied to that theoretical volume which will gradually be approached as improved transportation facilities serve to reduce the frictions to a practical minimum.

4. **Induced Traffic:** The added component of traffic volume which did not previously exist in any form, but which results when new or improved transportation facilities are provided.

Example: Referring to the previous discussion of "potential traffic," improvements resulting in added capacity, reduced cost or time of travel,

or greater comfort and convenience will normally increase the amount of travel so as to more nearly approach the theoretical maximum or "potential."

Where trips to a shopping center previously may have been made at the rate of one per month per family from a certain residential area, a new highway may result in weekly trips. A new super-highway will, in effect, bring cities closer together and increase the volume of trips between them.

A new highway where none existed before, as into a previously undeveloped national park, will also result in traffic volumes classified as "induced traffic."

Again referring to the previous section, "induced traffic" is synonymous with "released potential traffic."

5. **Shifted Traffic:** A component of traffic made up of trips whose desire lines have shifted due to a change in origin or destination.

Example: A new shopping center may become the destination of both shopping and work trips that were formerly made to other destinations. New highways may themselves have the power to cause shifts of this type. A new or improved highway connecting a residential area to a previously unpatronized shopping area may result in changing the shopping habits of the residents. This component is distinguished from diverted traffic in that new origins or destinations are involved rather than a mere diversion from one route to a new paralleling route with no change in the end points of the trip. It differs from induced traffic, in that even though it is new traffic on the route in question, it is made up of trips which previously existed on some other route.

6. **Facility-Created Traffic:** The component of traffic which makes the facility itself the object of the trip.

Example: When a new highway or bridge is opened to traffic, there is normally a considerable amount of traffic which uses the facility out of curiosity; to inspect and become familiar with it.

Usually this component of traffic is quite temporary, and total volumes soon stabilize at a normal level as a part of the daily travel pattern.

While a small component of facility-created traffic may always exist, it is difficult to isolate from recreational trips to other destinations, or from the larger component of "induced traffic."

7. **Translated Traffic:** Trips made from origin to destination partly by one mode of travel and partly by another, requiring a change enroute.

Example: Most air, rail, or water trips involve some travel by other

modes of transportation. Daily auto trips to fringe parking lots, followed by mass transit travel to the CBD are also included in this category.

Of greatest interest to the traffic and highway planner are the conversion factors used to estimate auto and truck trips based on the number of arriving or departing trains, buses, airplanes, or ships.

8. **Generated Traffic:** A general term which can be applied to any part of the traffic created by one or more land uses.
9. **Generator:** A place which due to its particular kind of land use creates traffic movement through a process of attraction.
10. **Generation:** Creation of traffic flow by an attractive force.

Discussion: The terms *generation* and *generated traffic* have often been used in a special sense to describe that new component of the traffic stream which results from the construction of new or improved facilities. The authors believe that this specialized component should have a specific designation, and therefore suggest the term "induced traffic" as defined above. This term has been so used by other authors.

The term "parking generator," to mention a parallel example, is already an accepted term in highway and traffic jargon. It refers to any land use that tends to attract vehicular traffic and, in doing so, creates a need for parking space.

In the same sense, the authors believe that "traffic generator" should be applied in a general way to any facility that creates or attracts traffic movement.

Furthermore, the sense of *attraction* is an important part of this general definition. The question naturally arises with regard to a home-to-work trip, for example, whether the residential area or the work-place should be called the generator. According to the authors' suggested definition, this question can be resolved by examining the *trip purpose*. A generator *attracts* traffic by satisfying (or having some possibility of satisfying) a *need* or *desire*.

This concept perhaps can be most readily understood by considering a simple example. Consider a busy housewife making a round-robin series of trips starting from home, going first to the central business district to shop, then to a doctor's office for medical treatment, then to a theater, then returning home. Each of the stopping points, including the home, was both origin and destination of individual segments of the round trip.

The first leg of the trip, to the central business district, had a "shopping" purpose. If we consider the CBD as the generator of the trip, trip purpose and destination are in close agreement. Similar agreement results if we consider trip purpose and destination for each of the subsequent legs of the trip, including the final trip home. (There is probably no stronger attractor or generator than *home*.)

A different picture results if we consider the origin in each case as the generator of the various trips. Is there any validity in considering the home as a generator of shopping trips? Perhaps, but consider further. Does the CBD have any inherent power to create trips to a doctor's office? Or do doctors' offices as a rule generate trips to movie theaters?

The concept of the destination as the generator of the trip, and, in substance, *of all land uses as attractors or creators of traffic movement* seems to offer the most in the form of a workable definition.

11. **CBD: Central Business District.**

CHAPTER TWO

LAND USE GENERATION

I. The Dwelling Unit and the Residential Area

The home or dwelling unit may be thought of as the primary origin of all daily traffic movement. The daily cycle of human activity begins in the home.

It is from there that the trips for work, business, or school originate. Additional trips may follow for shopping, recreation, and other purposes. Each trip¹ is made originally to a location that promises to fulfill its purpose. Unless occasions arise for other trips, the traveler returns home. Any number of trips may be made, but eventually the home is reached as the final destination.

The importance of the home as a trip origin or destination is illustrated by the fact that about 80 percent of all urban area trips are made either from or to the home. Only 20 percent are made between all other origins and destinations. Data to support this observation will be discussed later in this chapter.

The Bureau of Public Roads, Department of Commerce, recently tabulated a considerable amount of data from home-interview origin and destination studies made in 45 cities since 1945. Some of the basic data is shown in Table II-1, and certain ratios based on these data are shown in Table II-2. Data from four additional cities have been tabulated and added. The tables represent values for 49 cities in six population groups.

Data for four of the six population groups were obtained from a small number of cities. This may partially explain the lack of consistent variations between population groups. One might expect a consistent variation, but there is no reason at this time to make such an assumption with regard to the type of information presented.

There was an average of about 3.2 persons per dwelling unit,

¹ Unless otherwise noted, the term "trip" as used in this report refers to the one-way travel between points of origin and destination.

Table II-1

HOUSEHOLD DATA FROM POSTWAR HOME INTERVIEWS IN 49 CITIES

<i>Population Group</i>	<i>No. of Cities</i>	<i>No. of Dwelling Units</i>	<i>No. of Persons</i>	<i>No. of Vehicles</i>	<i>No. of Trips (All Modes)</i>
Over 1,000,000	4	1,986,432	6,269,271	1,023,922	10,088,132
500,000-1,000,000	5	1,204,808	3,759,567	879,512	6,899,761
250,000-500,000	2	260,586	789,038	164,725	1,462,365
100,000-250,000	22	1,028,746	3,352,608	728,082	6,419,820
50,000-100,000	10	219,088	785,361	144,459	1,332,229
25,000-50,000	6	68,461	231,652	50,937	533,324
TOTAL	49	4,768,121	15,187,497	2,991,637	26,735,631

SOURCE: Based on tables prepared by Bureau of Public Roads.

5.1 persons per vehicle, and 0.63 vehicles per dwelling unit. The number of daily trips per dwelling averaged 5.61. Calculated per vehicle they averaged 8.94, and per person, 1.76. The number of trips refers to trips by all modes of travel from all origins to all destinations. The average value of 1.76 trips per day per person is lower than that reported by F. Houston Wynn² who found an average trip volume of 2.1 trips per day per person in cities under 600,000 population. Part, if not all, of the discrepancy may be explained. Wynn corrected the trip volumes given in the origin-destination reports to agree with screen-line volumes. He did this by increasing non-work trip volumes by factors ranging from 1.07 to 1.80.

² Wynn, F. Houston, Study made at Bureau of Highway Traffic, Yale University, New Haven.

Factors Modifying Trip Volume

The ranges of values shown in Table II-2 indicate that the application of average values to any one city might result in considerable error.

Such data will have greater value when future research discloses methods of evaluating modifying factors based on social and economic characteristics of the city being studied. A few

Table II-2
TRAVEL AND OWNERSHIP RATIOS, 49 CITIES

Population Group	No. of Cities	Persons per Dwelling Unit	Persons per Vehicle	Vehicles per Dwelling Unit	No. of Trips All Modes		
					Per Dwelling Unit	Per Vehicle	Per Person
Over 1,000,000	4	3.39	8.66	0.61	5.47	13.83	1.93
		3.16	6.12	0.52	5.08	9.85	1.61
		2.65	4.63	0.39	4.25	7.57	1.27
500,000-1,000,000	5	3.31	7.36	0.94	7.16	9.97	2.22
		3.12	4.28	0.73	5.73	7.84	1.84
		2.75	3.42	0.45	4.48	7.09	1.35
250,000-500,000	2	3.11	5.46	0.68	6.14	9.07	2.07
		3.03	4.79	0.63	5.62	8.89	1.85
		2.97	4.39	0.57	4.87	8.56	1.57
100,000-250,000	22	4.16	6.97	0.95	8.72	16.05	2.57
		3.26	4.61	0.71	6.24	8.82	1.92
		2.55	3.14	0.45	3.49	5.51	1.10
50,000-100,000	10	3.90	10.20	0.81	9.46	15.91	2.67
		3.58	5.44	0.66	6.09	9.23	1.70
		3.18	4.19	0.35	3.69	7.80	0.95
25,000-50,000	6	3.84	5.74	0.87	9.34	12.86	2.77
		3.39	4.55	0.74	7.79	10.47	2.30
		3.10	3.67	0.61	4.92	8.10	1.41
All Cities	49	4.16	10.20	0.95	9.46	16.05	2.77
		3.18	5.08	0.63	5.61	8.94	1.76
		2.55	3.14	0.35	3.49	5.51	0.95

NOTE: Average values shown in roman type, high and low values shown in italics.

studies of this nature have been made. In a paper entitled "Socio-Economic Relationships of Highway Travel of Residents of a Rural Area,"³ Lorin A. Thompson and Carl H. Madden of the University of Virginia made the following observations:

The amount of travel of a family varies proportionally with the size of the income, and varies directly with the socio-economic level.

Among the total population of each county, clerical, professional, and government workers travel most and subsistence farmers travel least.

Owner-operators of established businesses were also high-travel families.

Vehicle ownership is directly related to travel; the more cars a family has and the newer they are, the more the family travels.

The study by Thompson and Madden was limited to Buckingham and Charlotte Counties in Virginia, neither of which had any community larger than 1,000 population.

In Charlotte County, about three-fourths of the population live on farms. In Buckingham County about half the population is on farms and another 30 percent depend for their livelihood upon timbering and slate mining.

Findings of a study of this type would not necessarily apply to areas having different characteristics, but it is possible that certain basic relationships will apply to urban and rural places alike.

Some of the findings of the study with regard to the relationships of daily trips and daily mileage to family income are shown in Figures II-1 and II-2, for Buckingham County only. With regard to this phase of the study, the authors say:

In both counties trips per day increase with income up to a level of about \$4,000 in Charlotte County and about \$5,500 in Buckingham County. Thereafter travel decreases with increasing income. The pattern of daily mileage for Charlotte County families shows the same peak at an income level of \$4,000. In Buckingham County the relation between income and mileage is direct for all incomes. In both counties the number of samples in the high-income group was small; thus sampling errors probably contribute to the difference found for these groups.

Thompson and Madden studied the relationship of travel to a scale of socio-economic status defined as follows:

Socio-economic status is a measure of the standard of living based upon the ownership of material goods. Since it reflects saving and the accumulation of

³ Reported in Bulletin 67, "Some Economic Effects of Highway Improvement," Highway Research Board, Washington, D. C., 1953.

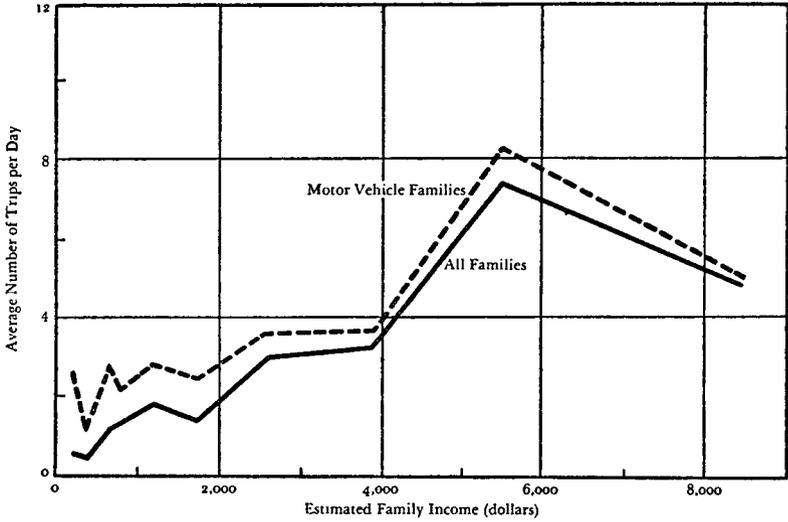


FIGURE II-1. Average number of trips per day for the 687 home-interview families by family income, Buckingham County.

SOURCE: Highway Research Board Bulletin 67, 1953.

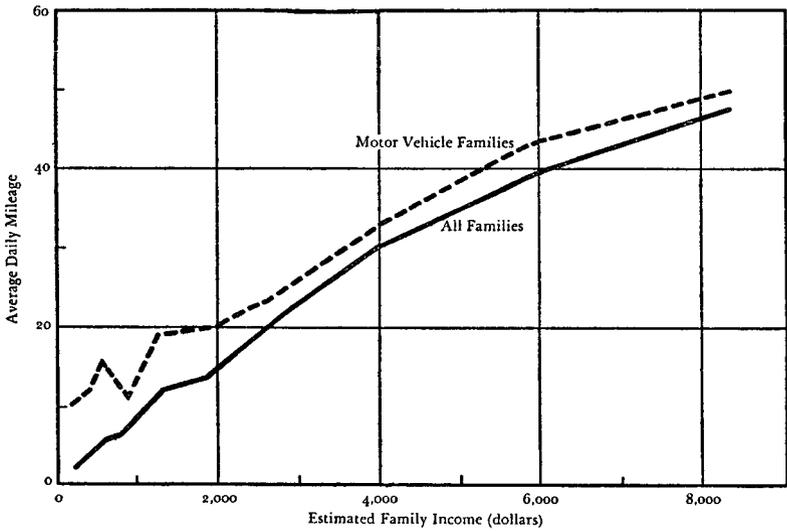


FIGURE II-2. Average daily mileage for the 687 home-interview families by estimated family income, Buckingham County.

SOURCE: Highway Research Board Bulletin 67, 1953.

capital goods, this scale appears to be a more stable indication of a family's social and economic position in the community than annual income, which may fluctuate for many reasons. Essentially, it is a method of ranking people by weighting the ownership of different items in proportion to the incidence of their ownership in a larger population like the United States. The eight items included in this scale in this study were: construction of house, rooms per person, lighting facilities, water piped into house, electric refrigerator, radio, telephone, and automobile other than truck. This socio-economic scale is a short form of the Sewell scale.⁴ Eight of the fourteen items which he used were available from the county studies.

The results of the socio-economic study are shown for Charlotte County in Figures II-3 and II-4. They indicate that travel is directly related to socio-economic status, and suggest that similar indices might be developed from urban travel studies.

Travel is generally considered to vary directly with vehicle ownership. Thompson and Madden have been quoted as making such a statement. In an investigation of the importance of vehicle registration in explaining volume fluctuations in trips of various types in urban areas, F. H. Wynn⁵ stated, "When mode of travel is disregarded it is found that high auto ownership and large family size are both related to higher-than-average trip generation."

The effect of car ownership on the number of trips made by individuals was studied briefly by the authors, and is illustrated by Figures II-5 and II-6. Home-interview data included in the origin and destination survey report for Houston, Texas,⁶ were used to calculate the number of persons per registered vehicle and the number of trips per person by all modes, for each of 67 zones outside the central business district. As the scatter of plotted points in Figure II-5 indicates, there appears to be a definite drop in the number of trips per person as the number of persons per vehicle rises from two to four. Above a population-vehicle ratio of 4 to 1, however, trips per person appear to be relatively constant and approach one trip per person per day as a lower limit.

⁴ See William H. Sewell's "A Short Form of the Farm Family Socio-Economic Status Scale," *Rural Sociology*, Vol. 8, No. 1 (June, 1943), pp. 161-170.

⁵ Yale study, see p. 9.

⁶ Houston Metropolitan Area Traffic Survey, Texas Highway Department, City of Houston, and Bureau of Public Roads, 1953.

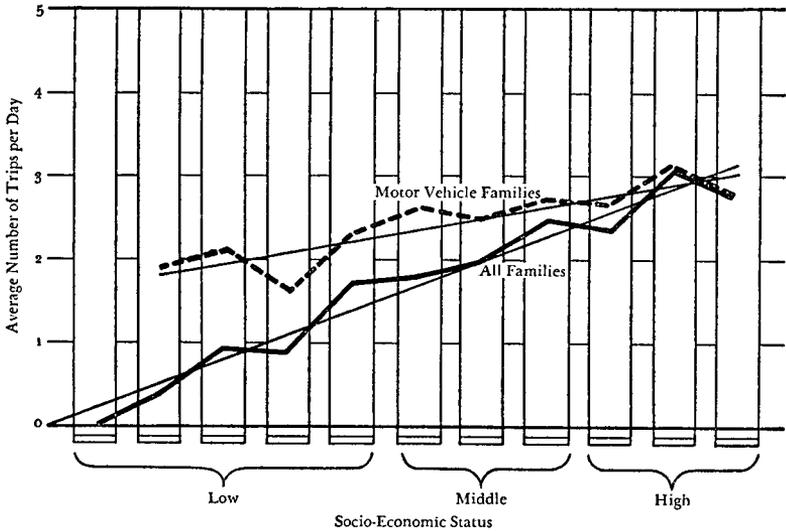


FIGURE II-3. Average number of trips per day for 783 home-interview families and the 516 motor-vehicle families classified by socio-economic status with linear least squares relationships plotted, Charlotte County. Low: 23 to 37. Middle 38 to 46. High: 47 to 55.

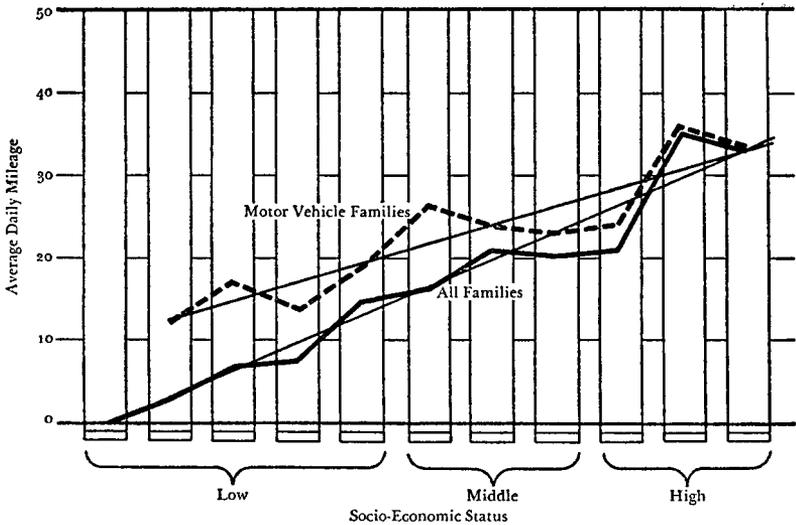


FIGURE II-4. Average daily mileage for the 783 home-interview families and the 516 motor-vehicle families classified by socio-economic status with linear least squares relationships plotted, Charlotte County.

SOURCE: Highway Research Board Bulletin 67, 1953.

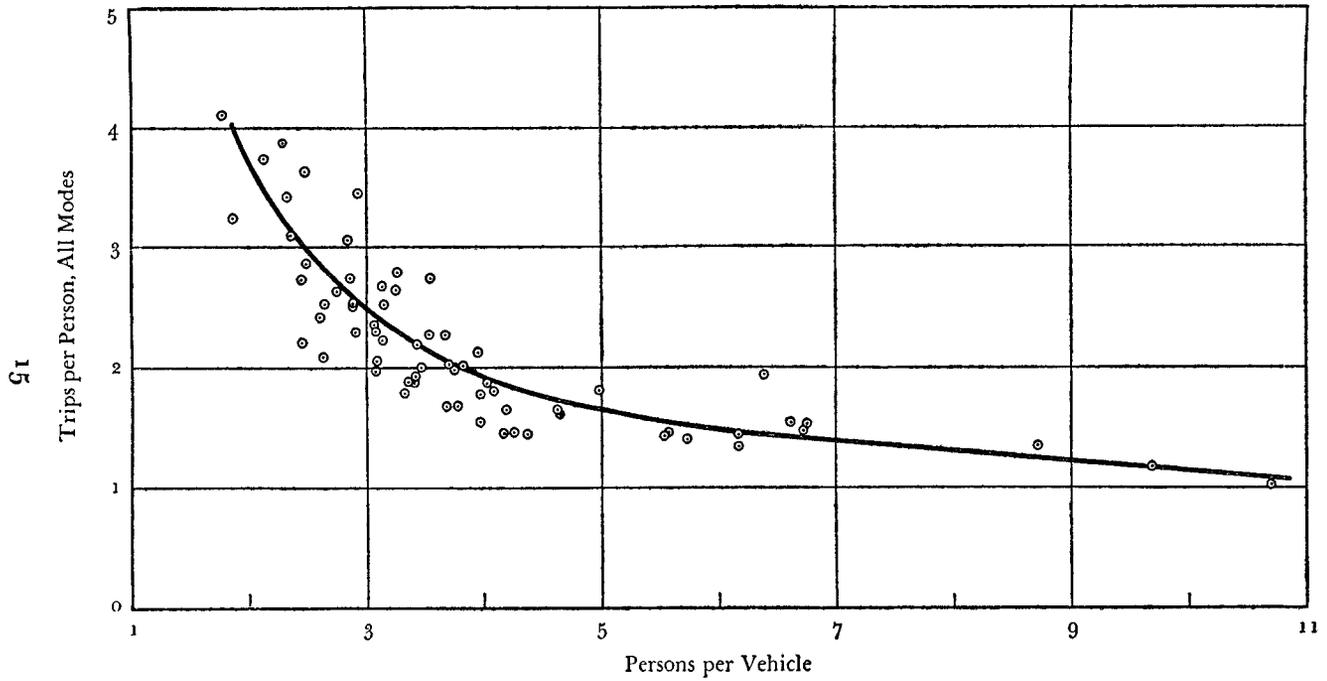


FIGURE II-5. Trips per person vs. persons per vehicle. 67 districts in Houston, Texas.

SOURCE: Calculated from Table A-5, Houston Metropolitan Area Traffic Survey Report, 1953.

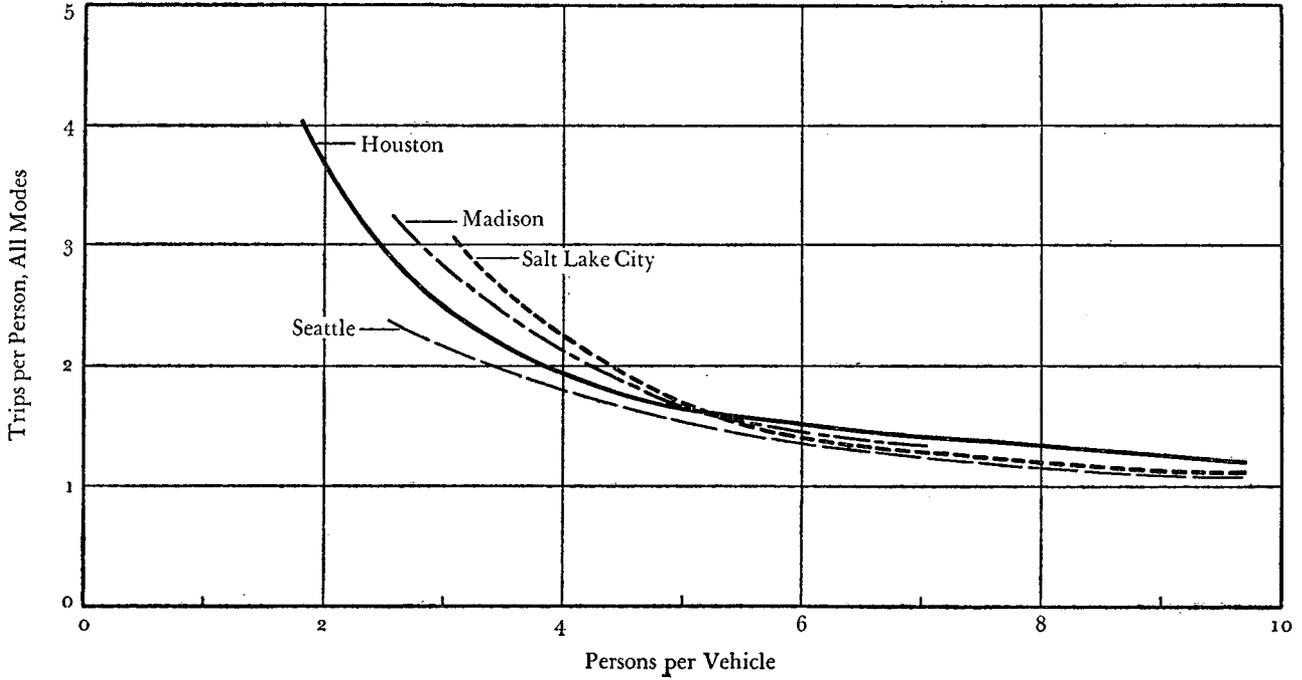


FIGURE II-6. Trips per person vs. persons per vehicle. 4 cities.

SOURCE: Origin-Destination Traffic Survey Reports.

Studies of data in origin-destination survey reports for Seattle (1946), Salt Lake City (1946), and Madison (1949) showed similar patterns. In all four studies, use was made only of data for zones outside the central business districts having a minimum of 200 dwelling units per zone. Free-hand lines of estimate for the four studies are shown in Figure II-6, indicating considerable uniformity for the cities studied despite differences in size, economy, and geographical location. Variations from the line of estimate in the individual studies were of about the same magnitude as those shown for the Houston study, Figure II-5.

Mode of Travel

Wynn did some work in relating trips by the various modes of travel to the population-vehicle ratio. One illustration in his study⁷ showed the curve of transit trips per 1,000 population versus vehicles per 1,000 population. His curve, re-plotted on the basis of persons per car, is shown in Figure II-7. Comparing this curve with that of Figure II-5, we see that while the total trips per person drop as the persons per vehicle ratio rises, the transit trips per person increase. The slope of the curve in Figure II-7 appears to drop off as it approaches its higher values, and indicates that it might be limited by a value of about 1.0 transit trip per person for high population-vehicle ratios.

The value of 1.0 trip per person per day represents a low level of travel approached when vehicle registrations are unusually low. It is useful as a point of reference in giving proportion to the more commonly reported values of about 1.5 to 2.5 trips per person per day. It might be considered as indicating the level of "essential" trips in most of our cities.

If, for the moment, we accept the values shown by the curves in Figures II-5 and II-7, an interesting table can be constructed. It should be remembered that the values from Figure II-5 are based on a study in only one city, and those taken from Figure II-7 are average values which do not reflect the variations among cities.

⁷ Yale study, see p. 9.

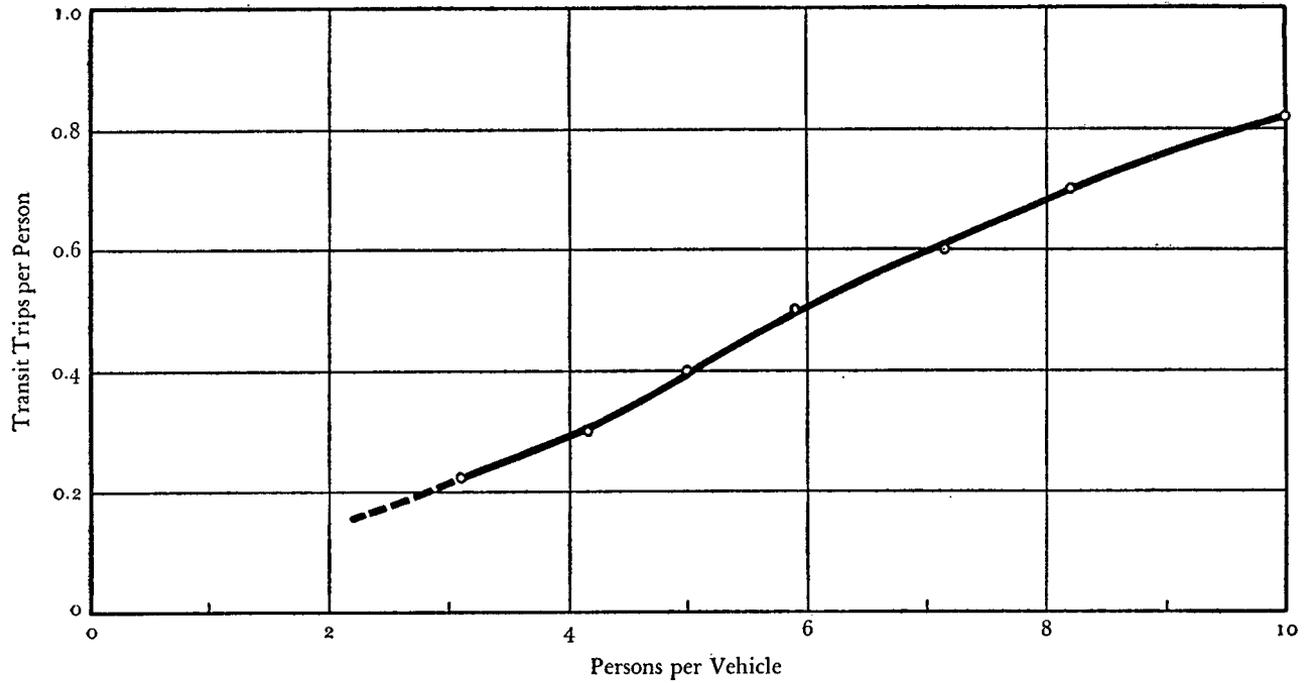


FIGURE II-7. Daily transit trips per person vs. persons per vehicle.

SOURCE: F. H. Wynn.

For illustrative purposes, however, Table II-3 has been derived from these two curves. The values in column (2) were estimated from the curve of trip frequency in Figure II-5. The transit trips per person, column (3), were estimated from Figure II-7. Column (4) is obtained by subtraction. Column (5) is the ratio per person, of nontransit trips to transit trips, and shows the variation in this ratio with changes in the population-vehicle ratio.

Table II-3
VARIATIONS IN TRIP FREQUENCY ACCORDING TO NUMBER OF PERSONS
PER VEHICLE, BY MODE OF TRAVEL

<i>Persons per Vehicle</i>	<i>Trips per Person</i>			<i>Ratio of (4) to (3)</i>
	<i>All Modes</i>	<i>Transit</i>	<i>Other than Transit</i>	
(1)	(2)	(3)	(4)	(5)
1	—	—	—	—
2	3.70	0.15	3.55	24 : 1
3	2.50	0.20	2.30	11.5 : 1
4	1.80	0.30	1.50	5 : 1
5	1.60	0.40	1.20	3 : 1
6	1.50	0.50	1.00	2 : 1
7	1.40	0.57	0.83	1.5 : 1
8	1.30	0.68	0.62	0.91 : 1
9	1.25	0.75	0.50	0.67 : 1
10	1.20	0.82	0.38	0.46 : 1

NOTE: For illustrative purposes only. See text.

SOURCE: Dwelling unit data from Houston Metropolitan Area Traffic Survey report (1953), and Wynn, F. H.

The ratios could be of use in urban traffic planning work, but as given here they should be used with discretion. They are presented chiefly for illustrative purposes, and are derived partly from inconclusive evidence.

Trip Purpose

Previously reference was made to tables of trip data compiled by the Bureau of Public Roads. The Bureau also tabulated trips by purpose, and obtained values shown in Table II-4. These

values are based on data from 38 cities having a total of 4,229,688 dwelling units and reporting a total of 22,776,019 trips by all modes for all purposes.

The first two columns of Table II-4 show purpose of trips reported in the 38 cities, and the trip purpose percentages, for those trips which were made from the home as the origin or starting point. Over 9 million home-origin trips were reported, representing 41 percent of the nearly 23 million daily trips reported from all origins to all destinations. An equal percentage of the total trips was reported from miscellaneous origins to the home as a destination. Thus a total of 82 percent of all trips reported was made either to or from the dwelling unit.

Table II-4
PURPOSE OF TRIPS ORIGINATING IN THE DWELLING UNIT

<i>Trip Purpose</i>	<i>In 38 Cities*</i>		<i>In 1,000 Dwelling Units (Hypothetical)</i>
	<i>No. of Trips</i>	<i>%</i>	
Work	4,093,724	43.9	1,010
Business	636,339	6.8	155
Social—Recreation	1,996,017	21.4	490
Shopping	1,110,276	11.9	275
School	451,474	4.8	110
All others	1,037,873	11.2	260
TOTAL	9,325,703	100.0	2,300

* From data tabulated by Bureau of Public Roads.

Referring to Table II-2, using the average value of 5.61 trips per dwelling, we can then say that a residential area of 1,000 dwelling units will produce about 5,600 trips by all modes for all purposes, from all origins to all destinations. Applying the average factor of 41 percent to this figure indicates that about 2,300 trips would originate in this residential unit of 1,000 dwellings. Applying the trip purpose percentages of Table II-4 to this figure gives average trip volumes, by trip purpose, for the 1,000-home residential-unit, as shown in the last column of Table II-4.

These values are based on average conditions. An obvious adjustment would be a correction for the population-vehicle ratio in the area studied. As the 2,300 trips were derived from the value of 5.61 trips per dwelling unit as given in Table II-2, they obviously correspond to the average values of 1.76 trips per person and 5.08 persons per vehicle, also given in Table II-2. These values conform to the curves of Figures II-5 and II-6 which in turn suggest the corrections that should be made for other population-vehicle ratios.

Of particular interest is the calculated value of 1,010 work trips per day originating in the 1,000 dwelling units. Wynn⁸ states, "The ratio of work trips to population for all mechanical modes of travel is found to be reasonably stable at about 0.63 work trips per person per day in cities up to 600,000 population."

From Table II-2, 1,000 dwelling units would house about 3,180 persons. Applying Wynn's value of 0.63 work trips per person to this figure, 2,000 work trips would originate from this group of dwelling units, compared with 1,010 trips previously calculated.

However, Wynn defined a work trip as any trip made from home to work, or from work to any other destination, so that the figure 2,000 must be halved for a true comparison. The two estimates then become almost exact.

Trips Originating in Residential Areas

Previous studies have shown that the level of vehicle ownership has a significant effect on the number of daily trips made. High passenger vehicle registration generally results in high total trip volume and low relative use of mass transit facilities.

In order to investigate this matter further, an analysis was made of trips reported in origin and destination surveys in 36 cities. The trips analyzed were those made by auto drivers, auto passengers, and transit passengers, from the home as a starting point. Walking trips, taxi trips, truck passenger trips, or others were not included.

⁸ Yale study, see p. 9.

The trips made in each of the 36 cities were analyzed to determine how the daily trips per 1,000 dwelling units varied according to the average number of vehicles per dwelling unit. Study was made of the effect of the vehicle registration level on the mode of travel and the number of trips made for various purposes.

As data for individual zones in these cities were not available, the study was based on over-all totals for each of the 36 cities, with regard to number of dwelling units, vehicle registration, and number of trips made by each mode of travel for various purposes. The average number of vehicles per dwelling unit used as a basis of comparison showed considerable variation in this group of cities, and ranged from 0.35 to 0.85.

Figure II-8 shows the variations in trips by the three principal modes of travel, according to the variations in vehicle ownership. As these curves show, increases in vehicle registration result in a general increase in total travel. Trips by private auto increase at a faster rate, however, at the expense of transit travel.

Figure II-9 shows the same curve of total travel divided into the major trip purposes. Work trips are relatively constant, but there is a slight increase at the lower end of the vehicle registration scale. On the assumption that low vehicle registration is normally an indication of low-income families,⁹ a greater number of work trips per family would seem reasonable.

Trips for all other purposes are made at increased rates as vehicle registration goes up.

The five sets of curves in Figure II-10 show the breakdown by mode of travel of the five principal trip-purpose categories. In all categories, the use of the auto is seen to increase with higher vehicle registration. The total travel increases for all purposes except work trips, discussed above. Transit travel seems to hold up fairly well for all categories other than work trips. Even so, transit work trips outnumber the combined transit trips for all other purposes at all levels of vehicle registration.

A few cities showed considerable variations from these average curves. From the standpoint of total volume, Honolulu, Phoenix,

⁹ An exception might be high-income apartment dwellers on the fringe of the central business district.

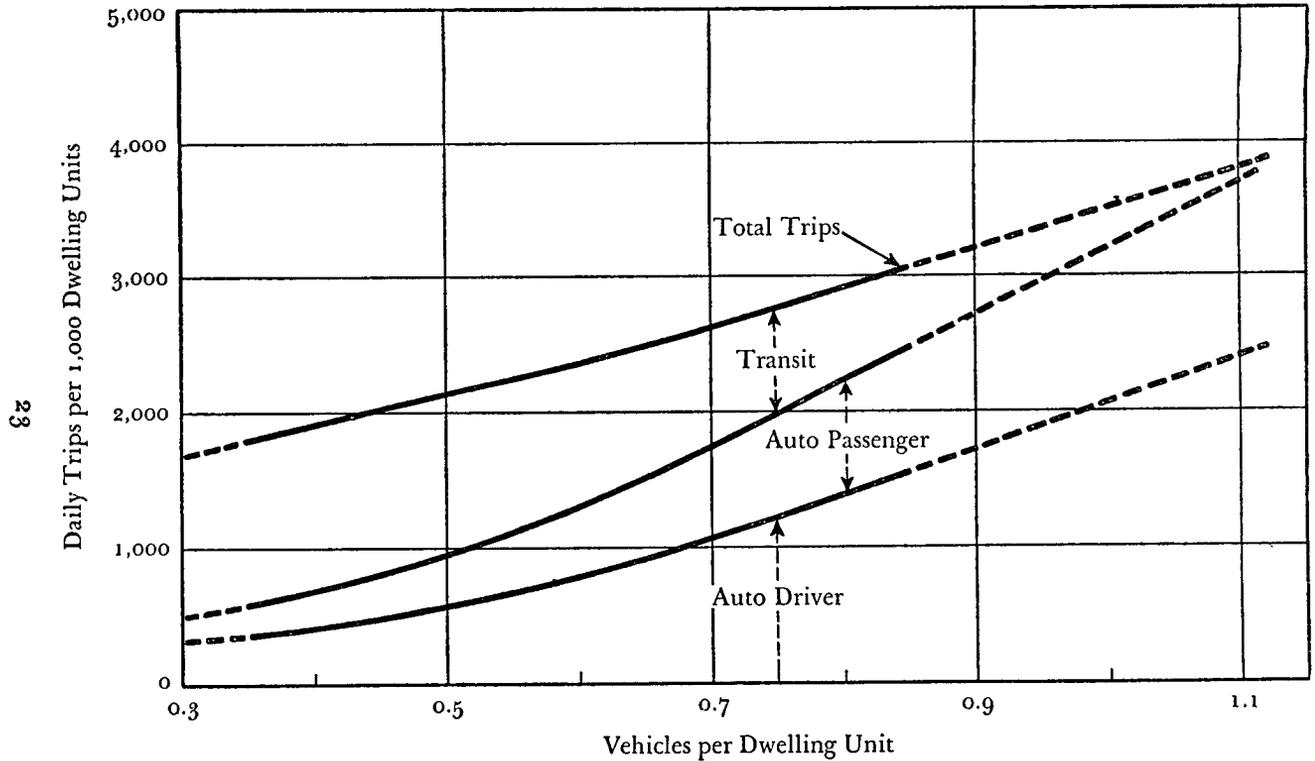


FIGURE II-8. Distribution of trips from dwelling units by mode of travel.

SOURCE: Origin-Destination Surveys of 36 Cities.

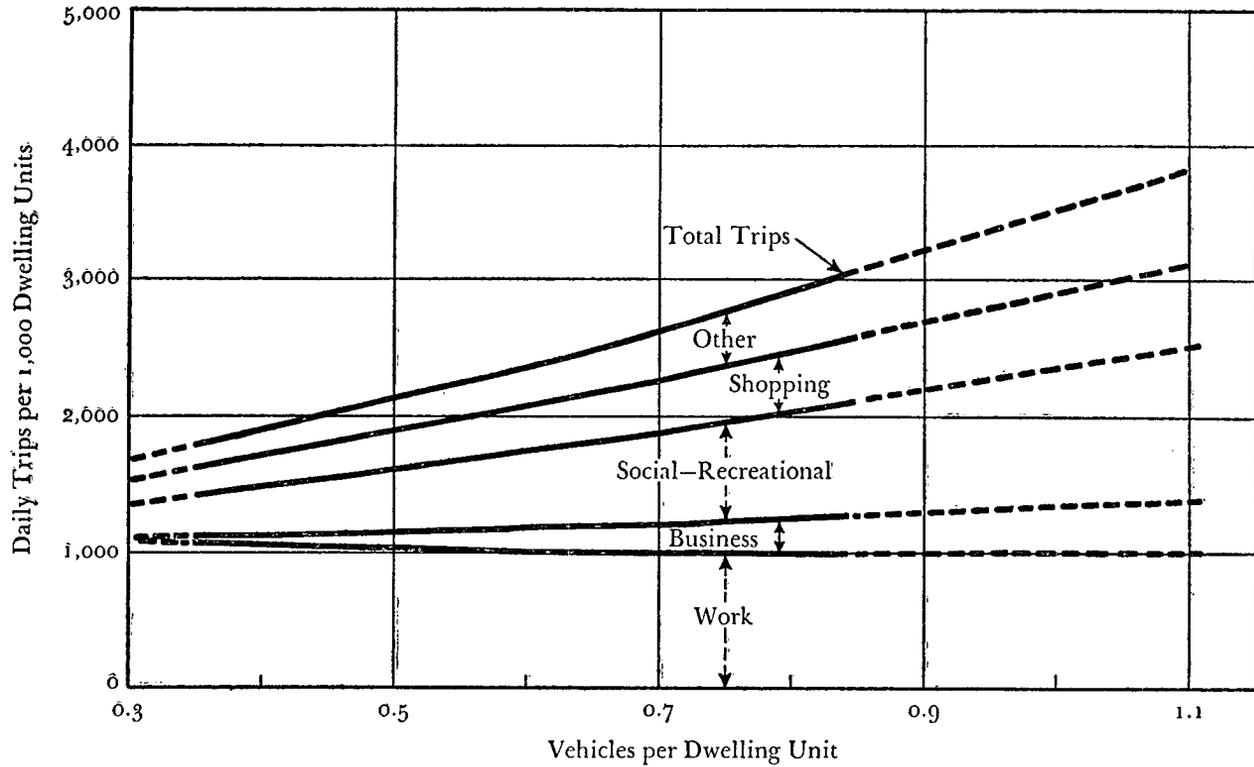


FIGURE II-9. Distribution of trips from dwelling units by purpose of trip.

SOURCE: Origin-Destination Surveys of 36 Cities.

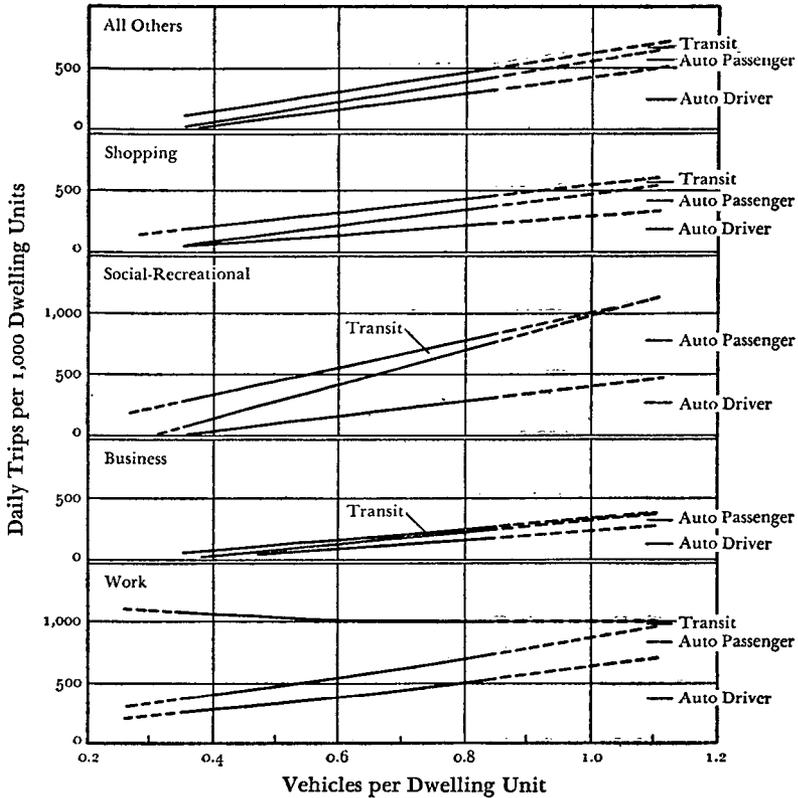


FIGURE II-10. Distribution of trips from dwelling units for various purposes, by mode of travel.

SOURCE: Origin-Destination Surveys of 36 Cities.

Grand Rapids, Macon, Columbus (Ga.), and Charleston, S.C., showed overall trip volumes considerably above other cities having the same vehicle registration rates.

In the work trip category, all cities seemed to show quite consistent tendencies, with no extreme variations from the general pattern of trip generation by the three modes of travel.

The analysis of business trips showed the three southern cities of Macon, Columbus, and Charleston far above the expected values. This might be due to a difference in study procedure or interpretation.

In the social-recreational trip category, Honolulu, Bay City, Muskegon, and Charleston showed abnormally high trip generation.

With regard to shopping trips, Columbus, Macon, Charleston, Phoenix, and Grand Rapids showed unusually high volumes of trips.

The classification "all other trips" included trips to school, to medical and dental offices, to serve passengers, to eat meals, and to change mode of travel. Unusually high volumes of trips were reported in Philadelphia, Columbus, Honolulu, and Phoenix. A high volume of trips for the purpose of "changing mode of travel" accounted for the bulk of the excess trips in Philadelphia, while trips to school and to serve passengers were reported at an unusually high level in the other cities.

It is difficult to explain the reasons for some of these outstanding variations from the normal patterns of trip generation. As suggested above, differences in reporting and interpretation of study data might account for some of them. Others might reasonably be expected, such as the "change mode" classification in Philadelphia, and the high rate of social-recreational trips in certain cities noted for recreational and vacation facilities.

More intensive study of the individual origin-destination survey procedures and of the peculiar characteristics of each of the cities would be required in order to explain more fully the variations noted.

The curves appear to be fairly representative of traffic generating patterns in the bulk of the cities, however, and if used judiciously with due regard for the outstanding characteristics of a city, useful traffic estimates can be made.

II. The Central Business District

As the historical center of the urban area from the standpoint of commerce and service activities, the central business district is the focal point of street traffic. The radial street patterns found in many cities are the result of years of travel to the market place and the village green.

The automobile has caused expansion in city areas, and has permitted relocations of business and employment centers because of the mobility of the shopper and the worker. It is not likely that the central business districts will ever disappear, though their present typical form may radically change. Suburban residential concentrations permit the development of shopping centers and will support other commercial, industrial, and professional activities. Every urban area also develops relatively specialized services which must operate from a central location. These, because of their dependence on large population pools, do not develop branches until a certain population distribution is reached. The types of business or services included in this category will vary according to the size of the city and its metropolitan area, and will become more specialized as the city increases in size.

Thus a city of 25,000 might have a variety of such services in the central core area, with only a minimum provision of grocery stores, drug stores, and other types of neighborhood-service establishments in the outlying areas. The central district will handle the distribution of most of the clothing, furniture, appliances, and other merchandise representing major purchases on the part of the consumer. Located in the central district will be most of the banking, business and professional offices, and places of entertainment serving the immediate area.

As the city increases in size, many of the services formerly located exclusively in the central district find it profitable to establish branches in outlying districts convenient to expanding residential areas. At the same time a larger city creates a demand for more specialized services which cannot be supported by smaller communities.

In our largest cities, the needs for daily living (usually called "convenience goods") and a good assortment of furniture, clothing and general merchandise ("shopping goods") can be found in centers located outside the central district. In addition, banking, medical and dental, automotive, entertainment, and other services can be found in each large concentration of population around the outskirts of the city. Within the central business dis-

trict are the largest department stores, specialty shops, main business offices, and many establishments of a specialized nature which are rarely found in smaller cities. The principal city of a large geographical area will generate traffic from several surrounding counties or even from surrounding states, because of its specialized attractions.

This attribute of exclusiveness of many of the services found in the central district may well account for many of the trips now made to such areas, trips which continue to be made in spite of discouraging traffic conditions.

The definition of exclusiveness should not be too rigidly drawn; an opportunity to compare and select from a large variety of goods may be presented only in the central business district. In this sense the district may not have an exclusive franchise to offer certain types of goods, but it generally provides the shopper with the opportunity for comparison shopping to a degree not possible in most outlying shopping centers.

This superiority in variety of goods and services, combined with the lure of exclusive offerings, continues to attract many shoppers to the downtown area.

It is not intended to overemphasize the importance of the CBD as a shopping place. The central business district is also an important employment center; in many cities it is the principal work place. In a study made in Washington, D. C.,¹⁰ it was found that, in 1948, 23 percent of all trips to the core area were for the purpose of shopping, and 46 percent were for work purposes. While much of the employment is obviously dependent on retail sales activities, the importance of the central business district as an independent employment center should not be overlooked. Detailed investigations of the types of activities carried on in central business districts are needed, along with correlations of such data with the number and purposes of trips made to these areas. Such studies would provide a better understanding of the relation between land-use and trip volume, and might suggest a basis for predicting future traffic according to trends in land use.

¹⁰ *Travel To Commercial Centers of the Washington Metropolitan Area*, Gordon B. Sharpe, Bureau of Public Roads. Bulletin 79, Highway Research Board. Washington, D. C. 1953.

Central Business District Trip Generation

Daily trips made to the central business district of a city will depend on such factors as the population of the city and its metropolitan area, distribution of population with regard to distance from the central business district, number of workers in the CBD, the level of vehicle ownership, adequacy of the public transit system, types of goods and services offered, and the effect of competing shopping and commercial areas. Other items might be added to this list.

The comparatively few studies made, however, have not produced a definitive list of factors which can be said to determine the total volume of CBD trips. No one has, as yet, offered a method of synthesizing all travel to the CBD on the basis of known data on population, vehicle ownership, family income, or other social, geographic, or economic facts.

A study of the daily movement of persons into the CBD's of large and middle-sized American cities was made by Donald L. Foley,¹¹ and published in 1952. Foley used cordon counts and data from origin-destination surveys to study the number of persons entering the CBD between the hours of 7 a.m. and 7 p.m. (including those passing through), the number having destinations in the CBD during the same time period, and the maximum accumulation of persons in the CBD, usually in the period between noon and 3 p.m.

He then expressed these measures in ratio form—as the number of persons per 1,000 metropolitan-district population—so as to permit comparisons between cities of various sizes. The problem of non-uniform definition of the CBD in the original traffic surveys was encountered by Foley.¹²

He dealt with it by using an adjustment procedure developed in collaboration with Gerald Breese such that standard entrance,

¹¹ Foley, Donald L. "The Daily Movement of Population into Central Business Districts." *American Sociological Review*, Vol. 17, No. 5, October, 1952.

¹² The problem of defining the CBD boundaries has been encountered by many researchers. For a recent study on this subject see "Delimiting the CBD," by Raymond E. Murphy and J. E. Vance, Jr., one of three papers in the pamphlet *Central Business District Studies* published by Clark University, Worcester, Mass., in January, 1955. Reprinted from *Economic Geography*.

Table II-5

STANDARDIZED MEASURES OF DAILY POPULATION MOVEMENT INTO CENTRAL BUSINESS DISTRICTS
BY CITY-SIZE GROUPS^a

Metropolitan District Population (in 1,000s)	Mean Number of Persons per 1,000 Metropolitan Population						Intermeasure Ratios		
	Entering CBD, 7 A.M.-7 P.M.		With Destinations in CBD, 7 A.M.-7 P.M.		In CBD at Time of Maximum Accumulation		Dest's to Entrants (Col. 5 + Col. 3)	Accum. to Dest's (Col. 7 + Col. 5)	Accum. to Ent. (Col. 7 + Col. 3)
(1)	N ^b	Ratio	N	Ratio	N	Ratio	(8)	(9)	(10)
100-249	(8/8)	665	(10/10)	253	(3/3)	115	.38	.46	.17
250-499	(11/8)	558	(1/1)	234	(4/4)	114	.42	.49	.20
500-999	(7/6)	481	(3/3)	235	(8/7)	108	.49	.46	.23
1,000-1,999	(7/5)	274	(1/1)	170	(2/2)	90	.62	.53	.33
2,000-2,999	(4/4)	213	(0/0)	...	(2/2)	52	...	...	.25
3,000 and over	(12/2)	201	(1/1)	107	(3/1)	71	.53	.66	.35
Totals ^c	(49/29)	399	(16/16)	189	(22/16)	92	.48	.48	.23

^a Traffic surveys for the years 1936-1940 and 1946-1950 were used as representative of contemporary, reasonably normal conditions. The war years, 1941-1945, were excluded since their ratios tended to be abnormally low. All ratios have been standardized, (1) adjusting for CBD acreage and (2) excluding pedestrian entrants.

^b In each pair of figures in the *N* columns the first figure represents the total number of traffic surveys used and the second figure represents the total number of cities used. In the total figures for these *N* columns, overlapping city figures have been eliminated.

^c The ratio column totals are arithmetic means of the 6 size-group figures, each group weighted evenly. In each of the three cases where there is no figure for the 2-3 million population group, the mean of the three smaller size groups was averaged with the mean of the two available larger size-group figures.

SOURCE: Foley, Donald L. "The Daily Movement of Population Into Central Business Districts." *American Sociological Review*, Vol. 17, No. 5, October 1952.

destination, and accumulation ratios could be computed. Thus, unusually small or large CBDs as defined for traffic survey purposes were adjusted to an empirically derived ratio of CBD acreage per 1,000 metropolitan area population.

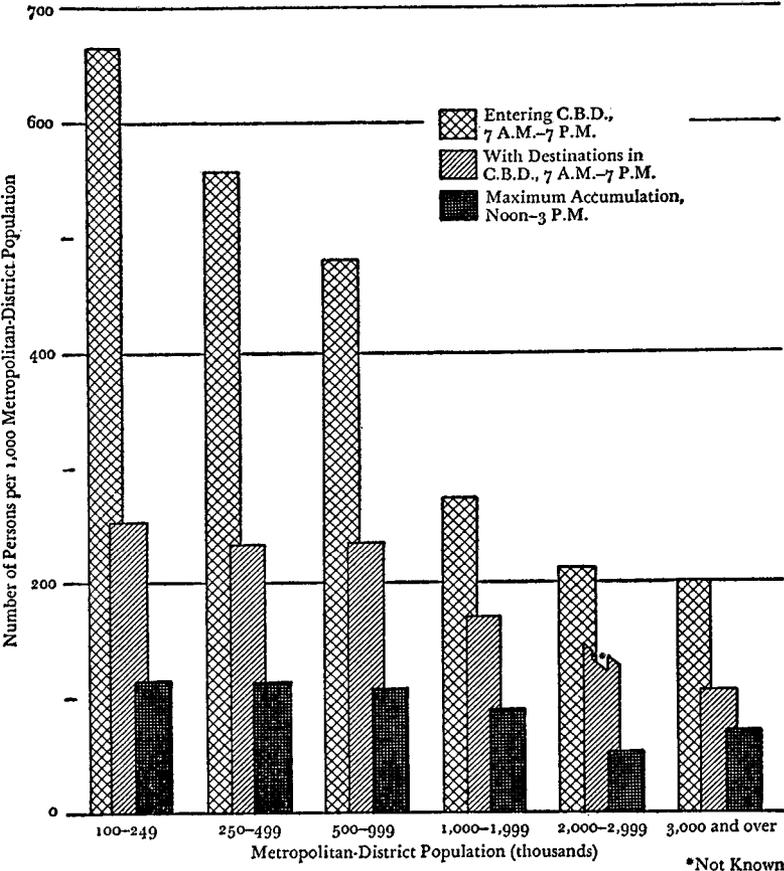


FIGURE II-11. Daily population movement into central business districts, by city size.

SOURCE: Donald L. Foley.

NOTE: Upper and middle portions of bars to be read as extending to 0 base line. Footnotes in source, Table II-5, apply.

Illustrations from Foley's study are shown in Figure II-11 and Table II-5, from which the figure was constructed.

Figure II-11 indicates that the entrance ratio (persons entering the CBD per 1,000 metropolitan area population) varies inversely with city size. Average figures for the various population groups ranged from 665 (cities of 100,000 to 249,000 population) to 201 (cities of 3 million or more population).

Average ratios for actual destinations in the CBDs show the inverse relationship, but to a lesser degree. The smallest population group averaged 253 CBD destinations per 1,000 population, while the largest (based on one city, Los Angeles) was 107 per 1,000 population.

Average accumulation ratios proved to be rather uniform from one city size group to the next, and the size-group averages varied from about 90 to 115 for the entire range of size groups. Again, an inverse relationship is indicated, and the largest city studied showed an accumulation of 70 persons per 1,000 population.

In commenting on the fact that the smaller cities showed higher destination and accumulation ratios than the larger cities, Foley says:

These higher ratios for the smaller cities apparently indicate a relatively greater concentration of functions in the smaller city's CBD. A question can be raised . . . as to how large a city must be before the various types of facilities do spread to outlying locations.

A study of traffic volumes and travel ratios in the central business districts of 67 cities produced the data shown in Table II-6.¹⁸ Of particular interest are the 8-hour inbound volumes shown in column (2). It should be noted that these are vehicular volumes and not volumes of people. They do not include transit or other passengers, nor are transit vehicles included.

It would be hazardous, therefore, to attempt to apply the figures to any particular city, even where transit volume is known. There is no way of gauging the effect of public transit in the 67 cities which produced the vehicular volumes shown in the table.

The inverse relationship of peak-hour traffic to city size is shown by the ratios in column (6).

¹⁸ Unpublished study by Bureau of Public Roads, Washington, D. C., 1954.

Table II-6

TRAFFIC VOLUMES AND RATIOS IN THE CENTRAL BUSINESS DISTRICTS OF CITIES IN EIGHT POPULATION GROUPS

Population Group (thousands)	Number of Cities	8-Hour Volume Inbound ¹	Avg.-Hr. Volume In and Out	Peak ½-Hr. Volume In and Out	Ratio, Peak to Avg. ½-Hr. In and Out	Volume per 1,000 Pop. Peak ½-Hr. In and Out	Vehicles passing thru CBD Percent ²	
							8 Hrs.	Peak ½-Hr.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
5-10	2	8,100	2,000	1,480	1.49	171	61	68
10-25	16	14,900	3,800	2,570	1.38	145	53	60
25-50	16	22,100	5,600	4,000	1.40	113	54	60
50-100	5	37,400	9,600	7,600	1.56	96	48	61
100-250	13	36,500	9,400	6,570	1.39	44	54	65
250-500	7	60,300	15,600	11,550	1.45	33	55	69
500-1,000	5	73,800	19,100	14,470	1.49	27	59	83
Over 1,000	3	85,500	22,700	17,500	1.54	13	52	74
All Groups	67						55	68

¹ 10 a.m.-6 p.m. All vehicles.² Percent of vehicles entering the CBD.

SOURCE: Bureau of Public Roads.

A report by F. Houston Wynn¹⁴ indicates that, in the twenty cities under 600,000 population studied by him, trip volume generated by the CBD varied directly with the size of the city, and averaged 0.64 trips per person for all persons living in the metropolitan area. Wynn's calculations were based on both inbound and outbound trips from the CBD, so that one-way volume (i.e. inbound trips to the CBD) would have averaged about 0.32 trips per person, or 320 trips per 1,000 population. This is an average rate of generation as applied to the surrounding area as a whole.

Wynn has indicated that additional study showed that the CBDs of still larger cities generate trips at a decreasing rate, and that the small sample of cities used in the above study in the 200,000 to 600,000 population range might be responsible for the failure to show a general decrease in trip generation with increase in city size.

Variations in CBD trip generation, according to distance or travel time have been the subject of a number of investigations. The previously mentioned study by Gordon B. Sharpe of the data gathered in the 1948 origin and destination survey of the Washington, D. C. metropolitan area showed that CBD trip volumes decreased, relatively, as distance from the CBD increased beyond two miles. The area surrounding the CBD was divided into concentric rings at 2-mile intervals. Trips by residents of the various rings were then analyzed as to mode of travel and purpose of travel, as related to their place of residence.

Figure II-12 compares trips to the CBD with all trips made by residents of the various areas. Percentages calculated from this diagram indicate that trips to the CBD account for about 34 percent of all trips from the 0-2 mile ring, and also that this value drops consistently to about 16 percent from the 8-10 mile ring.

Figure II-12 was constructed from the data in Table II-7. The table also shows that about 36 percent of all trips into the CBD came from the 2-4 mile ring, while only 1.9 percent came from the 8-10 mile ring. This information is of little significance in

¹⁴ Wynn, F. H. "Intra-City Traffic Movements." Bulletin 119. *Factors Influencing Travel Patterns*. Highway Research Board, Washington, D. C. 1955.

Table II-7

COMPARISON OF TRIPS MADE TO THE CENTRAL BUSINESS DISTRICT AND OF THE RESIDENT POPULATION OF CONCENTRIC RINGS
OF THE WASHINGTON, D. C. METROPOLITAN AREA—1948

<i>Ring</i>	<i>Distance from CBD (miles)</i>	<i>Resident population</i>	<i>Total of all trips to the CBD</i>	<i>Percent resident population</i>	<i>Percent of all trips to the CBD</i>	<i>Ratio, percent of trips divided by percent of population</i>	<i>Trips per 1,000 population</i>
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	0-2	271,477	65,396	24.5	26.2	1.07	241
2	2-4	354,912	89,804	32.0	35.9	1.12	253
3	4-6	305,163	67,957	27.5	27.2	0.99	223
4	6-8	145,627	21,911	13.1	8.8	0.67	151
5	8-10	32,681	4,814	2.9	1.9	0.66	147
		<u>1,109,860</u>	<u>249,882</u>	<u>100.0</u>	<u>100.0</u>		

SOURCE: Sharpe, Gordon B., "Travel to Commercial Centers of the Washington Metropolitan Area," Bulletin 79, Highway Research Board, Washington, D. C., 1953. Includes unpublished data supplied by Mr. Sharpe.

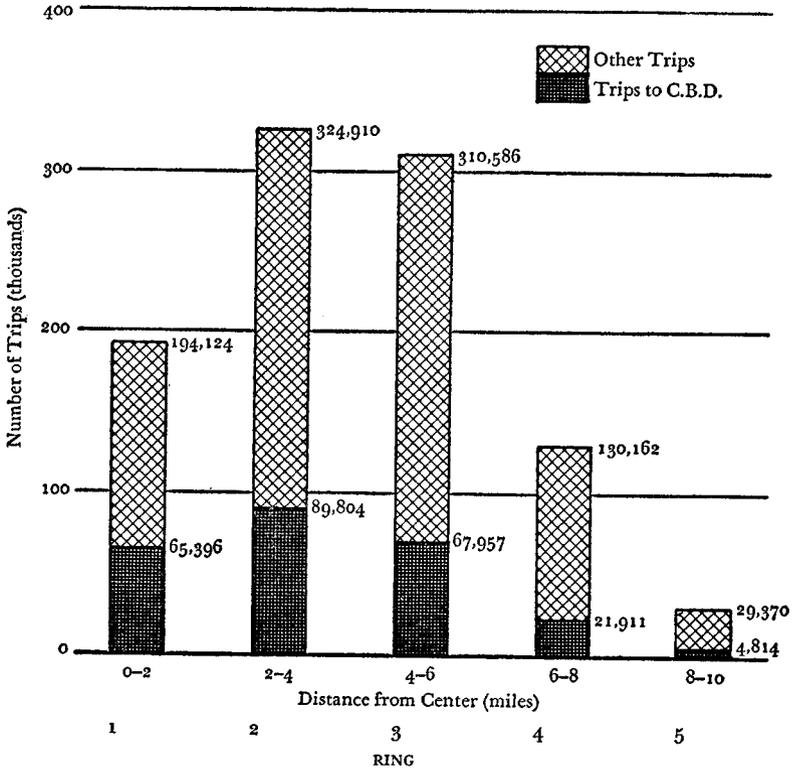


FIGURE II-12. Distribution of all trips vs. trips destined to central business district by residents of each ring. Average weekday—1948. Washington, D. C. metropolitan area.

SOURCE: Highway Research Board, Bulletin 79 (see Table II-7).

itself, as the population might also be distributed in the same ratio. The table shows, however, that the populations farther out from the CBD account for fewer trips per capita than do those to whom the CBD is more convenient. The ratio of percent of trips to percent of population shows that the areas within four miles of the CBD produce the greatest volume of trips in relation to population. The percentage of CBD trips and the percentage of population are about equal in the 4-6 mile zone, while the percentage of trips is only about two-thirds the percentage of population beyond the 6-mile ring.

As shown in Column (8), CBD trips per 1,000 population drop from about 250 within a four-mile distance to 150 or less beyond six miles from the CBD.

The effect of distance on the generation of CBD trips was also studied by Wynn,¹⁵ who reported (with regard to CBD trips per 1,000 population in nine cities):

The most striking feature is the consistent pattern of depreciation with distance. While a variety of slopes are shown, the number of trips generated drops off steadily beyond 2.5 miles from the center of the CBD. The rate of trip generation also appears to drop in the area close to the CBD, probably because zones immediately adjacent to the CBD generate a number of walking trips which are not reported in origin and destination surveys. Beyond two miles, the influence of walking trips has largely disappeared and the people living about 2.5 miles out generate the maximum number of trips by transit and auto. *For the cities studied, people at 2.5 miles generated from 500 to 600 trips per thousand per day. At 5.5 miles, a thousand people generated between 300 and 400 trips per day.*

The discrepancies between the CBD trip values obtained by Sharpe and by Wynn are partially due to the fact that Sharpe based his study on *inbound trips* while Wynn included both the *inbound and outbound trips*. Wynn's values for trips per 1,000 population would therefore be about twice those reported by Sharpe, assuming all other factors equal.

Trip Purpose

Most origin and destination study reports include trip purpose data for all internal and all external trips, but only rarely is such information tabulated separately for those trips made to the major traffic generator of every city—the CBD.

Data supplied by several state highway departments, city traffic engineers, and the Bureau of Public Roads are included in Table II-8. Unfortunately, trip purposes for all modes of travel were obtained for only two cities, and the usefulness of the table is thereby greatly reduced.

The table emphasizes the importance of work trips, as compared with trips for shopping or other purposes. Many trips to the CBD will be made for more than one purpose. The break-

¹⁵ Yale study, see p. 9.

Table II-8

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CBD, BY TRIP PURPOSE

<i>City</i>	<i>1950 Metro. Area Population, thousands</i>	<i>Work</i>	<i>Business</i>	<i>Combined Work and Business</i>	<i>Shopping</i>	<i>Social- Recreational</i>	<i>Other</i>
Detroit*	3016.2	49.7	10.1	59.8	17.5	10.1	12.6
Washington*	1464.1	45.6	8.2	53.8	23.4	13.8	9.0
Minneapolis-		46.0	15.0	61.0	10.0	8.0	21.0
St. Paul	1116.5	39.0	13.0	52.0	12.0	11.0	25.0
83 San Diego	556.8	32.6	14.1	46.7	9.2	—	44.1
Sacramento	277.1	38.1	10.3	48.4	11.3	8.2	32.1
Fresno	276.5	31.6	16.7	48.3	12.5	—	39.2
Stockton	200.8	26.2	18.9	45.1	13.4	—	41.5
Bakersfield	34.8†	—	—	41.6	22.9	5.0	30.5
Cumberland	36.3†	—	—	49.9	20.8	16.0	13.3
Frederick	18.0†	—	—	66.0	7.1	14.6	12.3
Salisbury	15.0†	—	—	55.6	11.9	16.4	16.1
Annapolis	10.0†	—	—	47.4	24.0	18.1	10.5

* Data for Detroit and Washington include transit trip purposes. Data for all other cities exclude transit.

† Incorporated city population.

down as shown is for the major trip purpose reported in the origin and destination survey.

In this connection it has been reported that downtown workers account for as much as one-quarter of the retail shopping volume in some cities.¹⁶ This fact would not be apparent from any analysis of major trip purposes.

Origin of Downtown Workers

In a study published in 1952, J. D. Carroll, Jr., makes the following observation:

“The residential distribution of persons employed in central districts tends to approximate that of the entire urban area population.”¹⁷

He supports this conclusion with dot maps of the city of Baltimore showing that total population and CBD workers are distributed in almost identical patterns throughout the city and metropolitan area. He also shows a striking similarity in the patterns of total population and CBD worker population, with regard to their distribution in concentric mile-zones measured outward from the CBD, in six major cities.

By way of contrast, Carroll shows that employees of off-center work places tend to be concentrated in residential areas in the nearby vicinity.

With this analysis of CBD worker distribution, a good start can be made toward synthesizing the pattern of trips to the CBD.

Starting with a known or estimated number of daily trips into the CBD, we can first assume that from 30 to 50 percent are work trips, and then distribute these uniformly throughout the residential areas in accordance with Carroll's findings.

Origin of Downtown Shoppers

A recent study of shopping habits and travel patterns in several

¹⁶ Reported in Highway Research Board Correlation Service Circular 271, March 1955.

¹⁷ J. Douglas Carroll, Jr. “The Relation of Homes to Work Places and the Spatial Pattern of Cities.” *Social Forces* Vol. 30, No. 3, 1952.

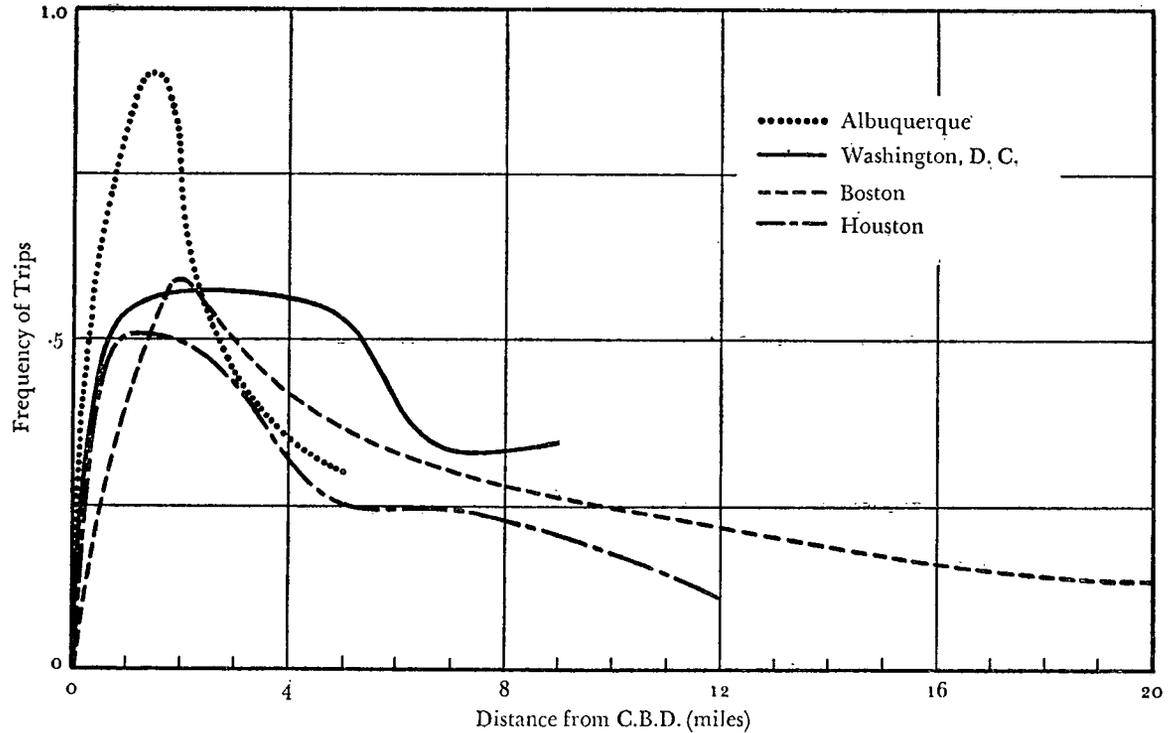


FIGURE II-13. Comparison of shopping trips per family made in a five-day week to the central business districts of four cities.

SOURCE: "Shopping Habits and Travel Patterns," Voorhees, Sharpe, and Stegmaier. Highway Research Board Special Report 11-B. Washington, D.C., 1955.

cities by Voorhees, Sharpe, and Stegmaier¹⁸ included a study of the frequency of shopping trips to the CBD as related to the distance of residence from the central area. In contrast to the distribution of the CBD worker population, it was found that CBD shopping trip origins are inversely related to distance. For Washington, D. C., Boston and Houston, CBD shopping trips per family reached a maximum rate of about one every two weeks from residences located within about two miles from the CBD, while families living from eight to ten miles out made such trips only about once a month. See Figure II-13.

Based on this study, we would be substantially correct in distributing a known or estimated volume of shopping trips in a constantly decreasing ratio to population, as distance from the CBD is increased.

The overall rate of CBD shopping-trip generation per 1,000 population would be relatively low in large cities where other shopping centers compete with the CBD, and relatively high in the smaller cities where the CBD is the center for all shopping goods and many of the convenience goods purchases. For example, Voorhees, et al, reported maximum CBD shopping trip frequencies of about one a week per family in Albuquerque (pop. 146,000) and over three a week per family in Appleton, Wisconsin (pop. 39,000).

Mode of Travel

The proportion of CBD travel by public transit is greater in large cities than in small ones. Population is not the only criterion and variations are found between different cities of approximately the same size. Such factors as passenger vehicle ownership, quality of transit service, density or compactness of the city pattern, and regional or local habits are important in accounting for these observed differences.

Wynn's¹⁹ study of travel to the CBD in twenty cities produced

¹⁸ "Shopping Habits and Travel Patterns," Alan M. Voorhees, Automotive Safety Foundation, and Gordon B. Sharpe and J. T. Stegmaier, Bureau of Public Roads. Special Report 11-B, Highway Research Board, Washington 25, D. C. 1955.

¹⁹ Yale study, see p. 9.

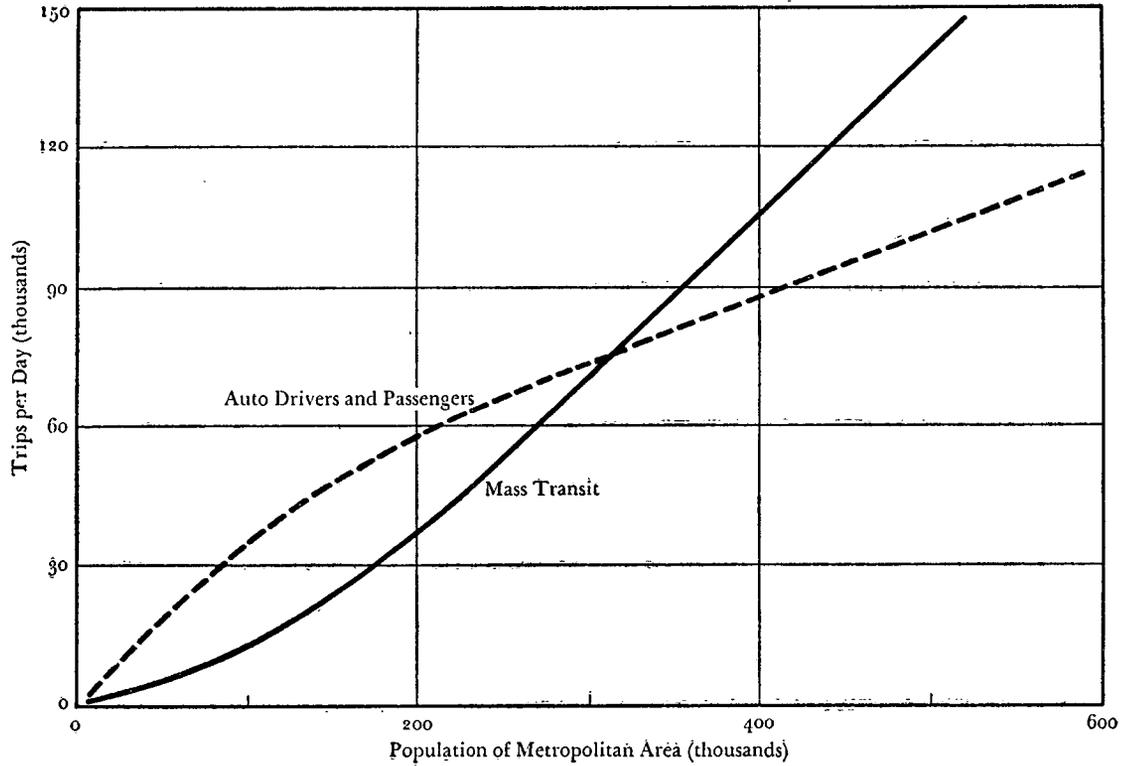


FIGURE II-14. Internal person trips generated in the C.B.D. 20 cities, 30,000-600,000 population. 1949.

SOURCE: F. H. Wynn.

the curves which have been combined in Figure II-14 and which are indicative of the division of travel mode with regard to city size, as of 1949. According to his calculations, auto travel was predominant below about 300,000 population, and mass transit travel became more important above that figure. Recent trends in the use of mass transit and private vehicles indicate that this relationship may be changing rapidly.

Mode vs. Distance

In Sharpe's study of the Washington, D. C. Metropolitan area²⁰ it was found that 62 percent of all trips to the CBD were made

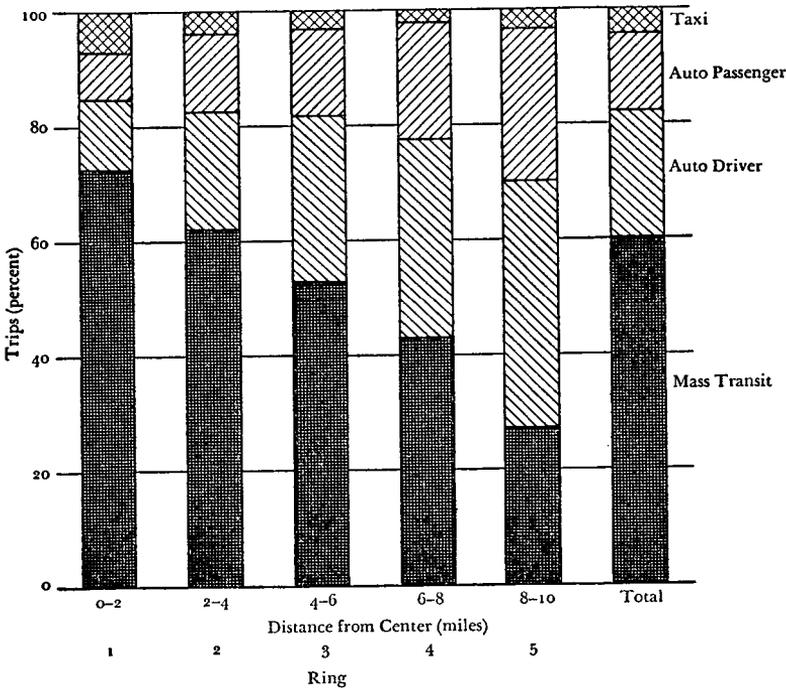


FIGURE II-15. Mode of travel of trips to the central business district by residents of each ring.

SOURCE: "Travel to Commercial Centers of the Washington Metropolitan Area," Gordon B. Sharpe, Bureau of Public Roads. Highway Research Board Bulletin 79, Washington, D.C., 1953.

²⁰ Ibid. p. 8.

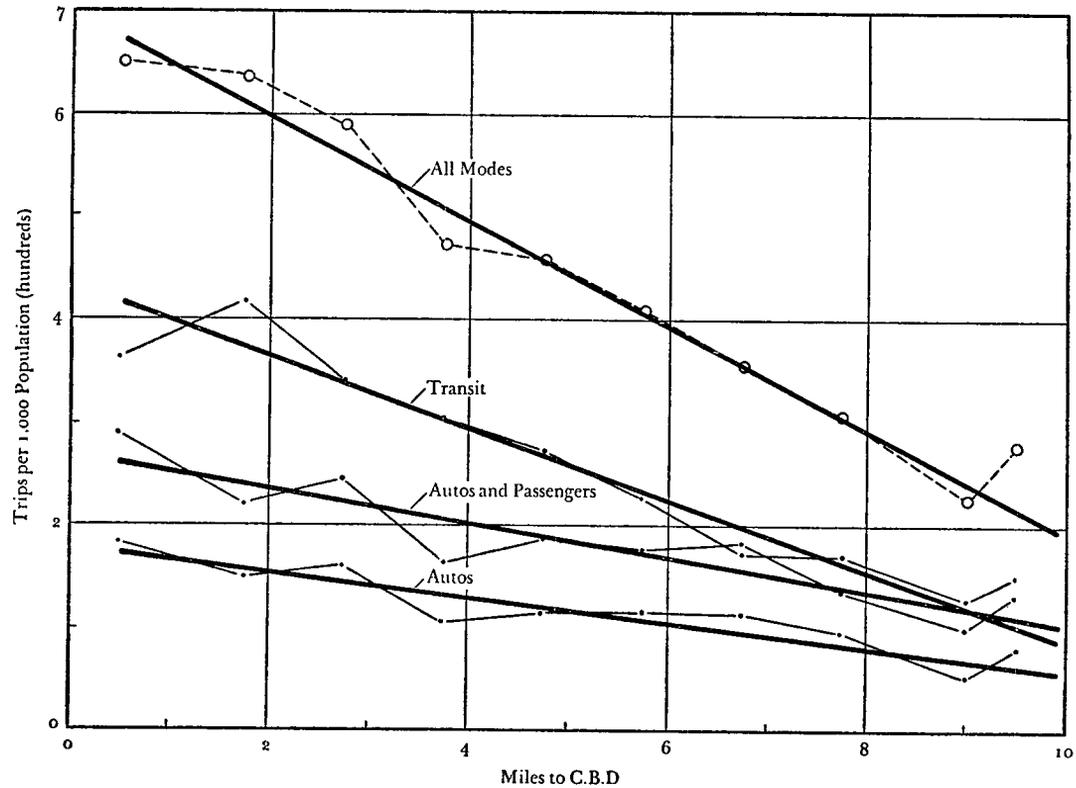


FIGURE II-16. Person trips generated by central business district by mode of travel. Seattle, Washington, 1946.

SOURCE: F. H. Wynn.

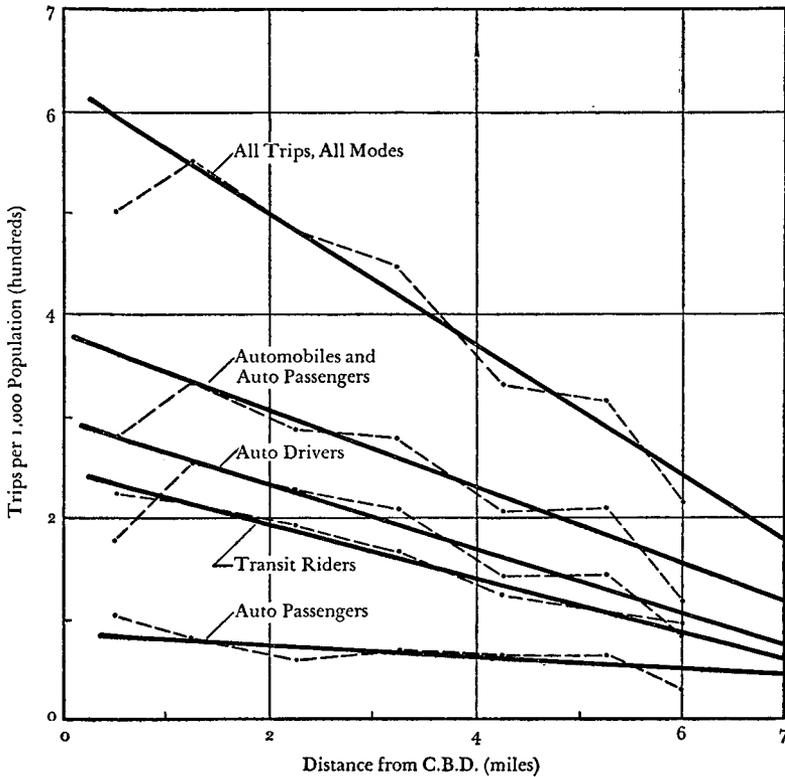


FIGURE II-17. Person trips generated by central business district by mode of travel. Tacoma, Washington, 1948.

SOURCE: F. H. Wynn.

by mass transit. When distance from the center was taken into consideration, it was found that the use of mass transit decreased rapidly with length of trip. As shown in Figure II-15, over 70 percent of the trips from within two miles was made by bus and street car, while the same percentage was made by automobiles from beyond eight miles.

Transit travel by the metropolitan population is limited by the physical limits of the transit system.

The division, by mode of travel, of trips to the CBD in the city of Seattle is shown in Figure II-16, from Wynn's Highway

Research Board paper. Transit travel is shown to exceed travel by private passenger car within a distance of nine miles from the CBD. Whereas transit trips would end at the limits of the transit system (except for some inter-city and suburban lines), trips by private passenger car could extend indefinitely, gradually decreasing as trip distance increased.

A similar illustration based on origin and destination data from Tacoma, Washington, is shown in Figure II-17. In Tacoma, with a population of about 140,000 at the time of the study, travel by private automobile was greater at all distances from the CBD.

Additional study is needed of the complexities of CBD trip generation with regard to city size, trip purpose, travel mode, and distance. Most studies to date have been based on information from a small number of cities. While general relationships have been fairly well explored, additional data are needed to refine the values thus far obtained.

Estimating Auto Travel to the CBD (Wynn Method)

A significant result of the study by Wynn²¹ is his proposed method of estimating the number of trips per car per day generated by the CBD. The analyst must know the population and the vehicle registration by zones within the city, and estimates of total driver trips are figured by use of the charts shown in Figure II-18a (effect of city size), Figure II-18b (effect of population-vehicle ownership ratio), and Figure II-18c (effect of population compactness). The fourth variable, distance from the central business district, is represented by a series of curves in each drawing.

Wynn's discussion of the use of the charts is as follows:

Data for any city in the population range 50,000 to 600,000 may be evaluated by these three charts (values based on data from the only city larger than 600,000 are regarded as tentative). Readings from Charts A and B are simply added and their sum reduced by the value determined from Chart C. The result is the average daily volume of trips generated in the

²¹ Wynn, F. H. "Intra-City Traffic Movements," (see p. 34).

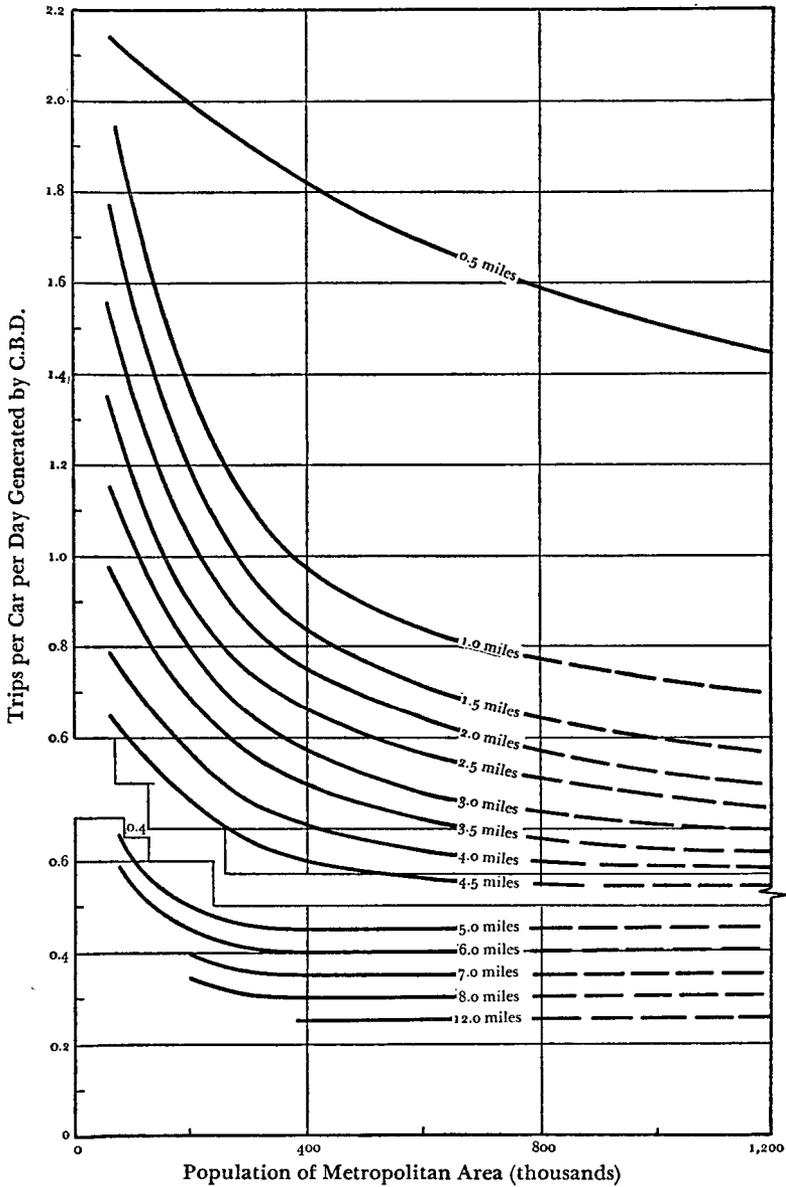


FIGURE II-18a. Automobile driver trips generated by the central business district. Measure of city size for urban areas, 50,000 to 600,000 population. SOURCE: F. H. Wynn.

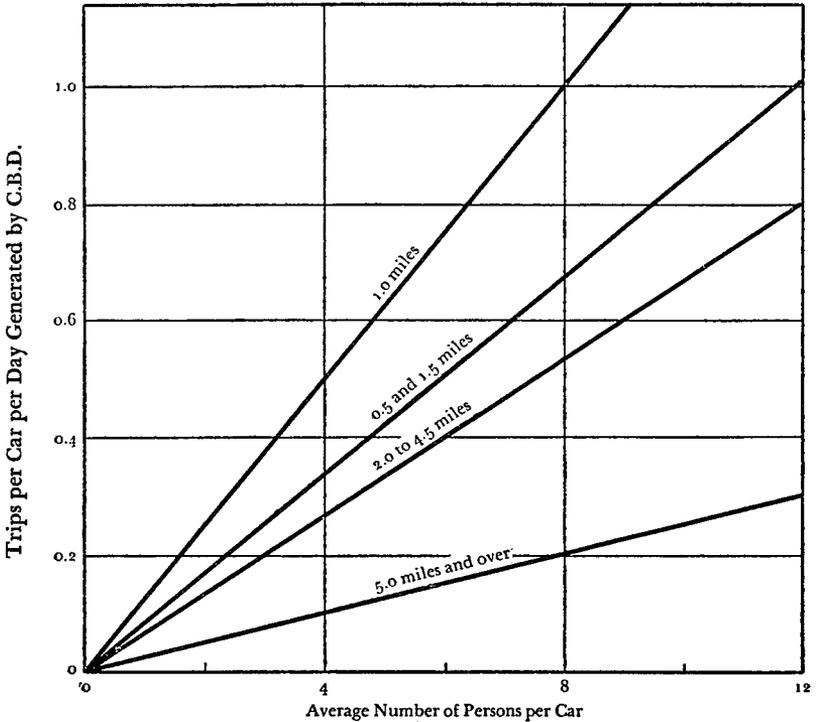


Chart B

FIGURE II-18b. Automobile driver trips generated by the central business district. Measure of population—vehicle ownership ratio.

NOTE: Values obtained from this chart to be added to values obtained from Chart "A."

SOURCE: F. H. Wynn.

central business district by each motor vehicle regularly garaged in the particular zone or group of zones at the designated distance.

The information needed to measure the internal generation of automobile trips by the central business district consists essentially of population and vehicle ownership data. Evaluated by the set of charts just described, the pattern of residential termini can be quickly established. If this information is to be of realistic value to the traffic or planning analyst, a complex breakdown of the residential community is desirable—perhaps as many as 50 or 60 zones or tracts of nearly equal size or population. The population and vehicle ownership in each zone should be carefully determined (for this reason census tracts may prove to be a convenient base). The centroid of population distribution should then be established in each zone and the shortest distance

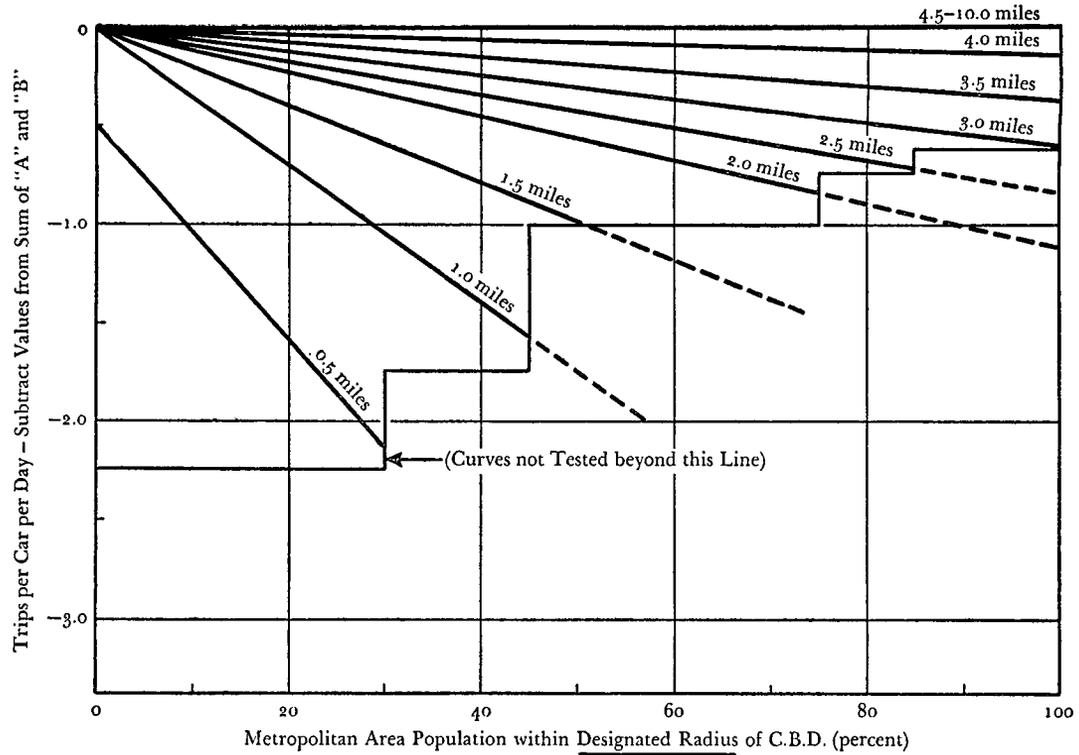


Chart C

FIGURE 18c. Automobile driver trips generated by central business district—measure of city compactness "C".

NOTE: Subtract values determined on this chart from the sum of values extracted from Charts "A" and "B."

SOURCE: F. H. Wynn.

between that centroid and the center of the central business district determined, as measured along existing streets. Population compactness and the population-vehicle ownership ratio for each zone must also be computed. These data are sufficient to make the estimates described.

A better estimate of residential trip termini can be made if the number of central business district auto trips generated by metropolitan area residents is known. A parking turnover study conducted at curb and off-street facilities can supply this information provided care is taken to ascertain the proportion of trips generated beyond the metropolitan area limits. The known volume of internal central business district auto trips thus obtained may be compared with the total estimate derived from the graphic formula and the volume of movement ascribed to each zone raised or lowered in direct proportion to the difference between estimated and actual volume.

III. The Off-Center Commercial Area

Development of Shopping Centers Outside CBD

As cities increase in size, retail sales establishments outside of the central business district gain importance as business centers and traffic generators. In small cities these establishments consist largely of the neighborhood grocery, drug store, or small service establishment.

Unplanned groups of neighborhood stores under separate ownerships develop as cities grow, and eventually there appears the planned shopping center with uniformity and harmony in architecture, integrated parking areas, and single ownership.

The development of secondary shopping centers is a natural one. Expanding residential developments are an invitation to the retailer to bring his merchandise to the consumer, rather than to expect the consumer to travel increasing distances, usually through congested areas, to make his purchases.

The study by Voorhees, Sharpe, and Stegmaier²² suggests that the tendency to develop suburban shopping centers has been well established in cities of 150,000 population and over, based on a study of the expansion of downtown department stores into suburban branches. This movement is apparently growing, even in cities below this size.

²² Ibid, p. 11 of the original study.

Importance of Outlying Shopping Centers

In an article²³ in the *Traffic Quarterly* of April, 1954, Larry Smith discussed the division of retail trade between central business districts and suburban districts:

Analysis of the retail store areas in more than one hundred cities of the United States indicates that the percentage of retail development in the suburban community bears a fairly close relationship to the total population. The proportions between central and suburban districts seem to vary within reasonably close limits for similar size cities, depending apparently upon location, rate of growth, and quality of the public transportation system.

In cities of fewer than 25,000 people this proportion may be 25 or 30 percent, representing largely the food, corner drug-store, and other very limited retailing in the residential suburbs. The percentage increases as the population increases and in typical cities of 500,000 population, we find that between 50 and 60 percent of the total retail space is located in the suburban communities at which time nuclei have been established at points of intersection of the public transportation system. Such nuclei contain variety stores, a limited number of apparel stores, hardware, and similar classifications of merchandise which almost characteristically throughout the United States are sold in major volume close to the place of residence.

In still larger cities the proportion of retail business in the suburban area increases to a considerable extent reaching more than 70 percent in cities of more than a million population.

Table II-9, from Smith's article, shows the division of retail space between CBD and suburban districts in six cities. Table

Table II-9
DIVISION OF RETAIL SPACE BETWEEN CENTRAL BUSINESS DISTRICTS
AND SUBURBAN DISTRICTS IN 6 CITIES

	Metropolitan Area Population	Total Retail Space 1952 sq. ft.	Retail Space in Central Business District sq. ft.	Percentage Central Business District	Percentage in Suburban District
Wichita	194,047	3,826,000	2,076,000	54.26	45.74
St. Paul	361,017	5,558,000	2,909,000	52.34	47.66
San Antonio	449,521	7,368,000	3,525,000	47.84	52.16
Miami	458,647	9,756,000	3,035,000	31.11	68.89
Portland	512,643	8,285,000	3,542,000	42.75	57.25
Minneapolis	624,084	9,949,000	4,752,000	47.76	52.24

SOURCE: Larry Smith and Company—Field Work.

²³ Smith, Larry. "Maintaining the Health of Our Central Business Districts." *Traffic Quarterly*, April 1954. The Eno Foundation, Saugatuck, Conn.

II-10, from the same article, shows an analysis of retail trade, by dollar volume, in CBD and suburban districts of three of our

Table II-10

DIVISION OF RETAIL SALES VOLUME BETWEEN CENTRAL BUSINESS DISTRICTS AND SUBURBAN DISTRICTS IN 3 LARGE CITIES			
	<i>Los Angeles</i>	<i>Philadelphia</i>	<i>Cleveland</i>
Population in Metropolitan Area	3,996,946	2,922,470	1,383,599
Percentage of Dollar Retail Volume 1948 Done in Sub- urban Districts			
<i>Merchandise Categories</i>			
Food	96%	95%	96%
Department Store	68%	36%	19%
Variety	78%	74%	62%
Apparel	77%	55%	46%
Furniture	87%	79%	75%
Hardware	98%	95%	94%
Drugs	87%	87%	87%
Eating and Drinking	86%	78%	78%
Other	72%	79%	73%
Total	86%	75%	71%
Percentage in Central Business District	14%	25%	29%

SOURCE: Larry Smith and Company (from U.S. Census).

largest cities. A large part of sales in all merchandise categories takes place in suburban areas, and the increase in such sales with increase in city size is strikingly consistent.

Outlying shopping centers thus attract a considerable part of the daily volume of shopping trips in medium and large cities, and are an important consideration to the planner or traffic engineer in estimating or predicting travel patterns.

Frequency and Distribution of Shopping Trips

Two important conclusions with regard to frequency of shopping trips were made in Highway Research Board Special Re-

port 11-B, "Shopping Habits and Travel Patterns." They can be stated as follows:

1. *Shopping goods* trips are made at the rate of about one a week per family, divided between the central business district and outlying shopping centers, varying with the relative size and location of the competing centers.
2. *Convenience goods* trips are made at a rate which apparently varies in accordance with vehicle ownership, and are usually made to the neighborhood store or shopping center nearest the place of residence.

The apparent effect of distance in reducing the frequency of shopping trips to the CBD was illustrated in Fig. II-13. One might expect that greater distance of travel alone would tend to reduce the frequency of such trips.

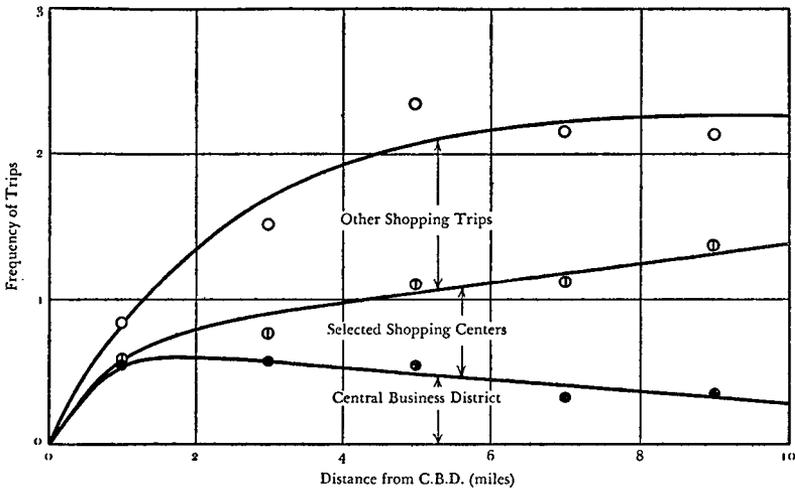


FIGURE II-19. Shopping trips per family made to the C.B.D. and to selected shopping centers in a five-day week, Washington, D. C.

SOURCE: Highway Research Board Special Report 11-B, 1955.

The competition of outlying shopping centers is probably the main cause of the drop-off, however, as illustrated in Fig. II-19. As this diagram shows, the decrease in the number of trips to the CBD is accompanied by an even greater increase in the number of trips made to other shopping centers. While trips to outlying centers predominate beyond about five miles from the

CBD, the CBD still exerts an important pull at the limits of the study area. The greater selection of goods displayed in the CBD makes it an important shopping center for a large surrounding area.

The increase in the number of shopping trips with the increase in the number of cars per dwelling unit is illustrated in Fig. II-20. The frequency of trips shown in this figure includes both shopping goods trips and convenience goods trips. Assuming that shopping goods trips remain fairly stable at one per week per family, the increase in trips corresponding to high vehicle ownership will apply primarily to convenience goods trips.

The curves for Appleton, Wisconsin and Houston, Texas show higher trip frequencies than those for the sections of the Washington, D. C. area. This seems in line with previous findings that trip frequency per capita is generally higher in smaller cities.

A typical frequency pattern of shopping trips to suburban centers of various sizes is shown in Fig. II-21, from Highway Research Board Special Report 11-B. Trip frequencies for shopping goods are shown to vary directly with the size of the center and inversely with the time-distance of travel, while the greater frequency of convenience goods trips is restricted to a smaller area around local centers.

Area of Attraction

The area from which a shopping center will attract customers is determined partially by travel time and partially by existing competition. Obviously, there is an upper limit to the amount of time a person will spend in traveling to and from a shopping place. This limit will vary with the type of goods sought.

Trips for food and convenience goods are usually short, primarily because of the wide distribution of standardized products throughout all well-populated areas. Shoppers are inclined to allow more time for travel in search of shopping goods. The extra time and inconvenience is of less importance than the opportunity to compare and choose from an adequate array of goods.

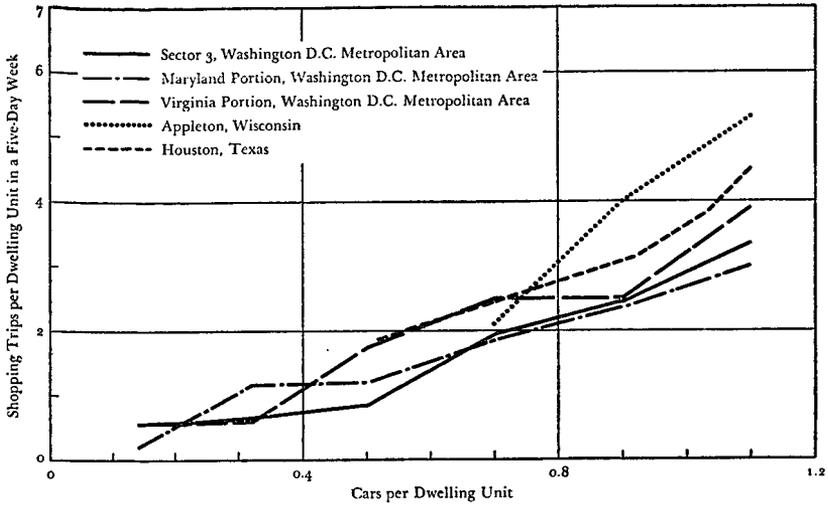


FIGURE II-20. Relationship of shopping trips to car ownership.

SOURCE: Highway Research Board Special Report 11-B, 1955.

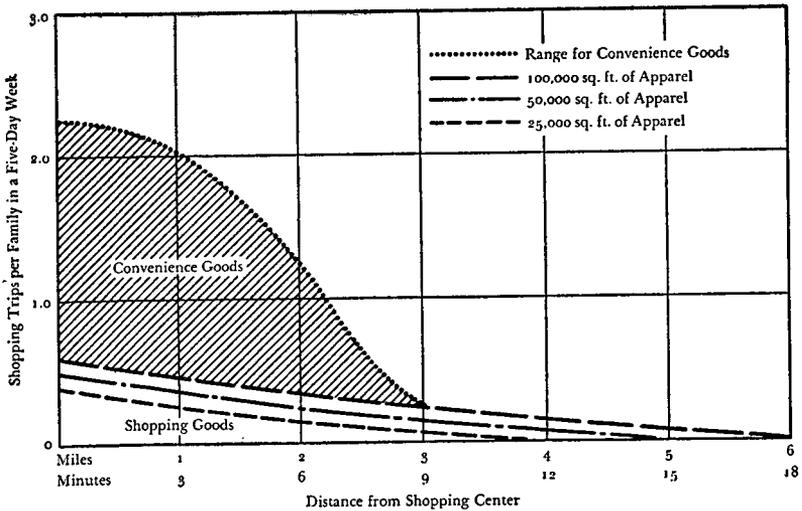


FIGURE II-21. Typical frequency pattern for shopping trips to shopping centers of various sizes.

SOURCE: Highway Research Board Special Report 11-B, 1955.

Sharpe's study of the Washington, D. C. area²⁴ included an analysis of the driving time to various shopping centers from the customers' place of residence. Six centers attracted 80 percent of their customers from within 10 minutes driving time, another six attracted 80 percent of their customers from within a 15-minute zone, and two attracted 80 percent from within a 25-minute zone.

An area defined by 30 minutes driving time would have included from 95 to 99 percent of the customers of these centers.

None of the centers included in Sharpe's study could be classified as regional shopping centers. Their areas of attraction were limited by the relatively small offerings of shopping-goods merchandise.

According to Kenneth C. Welch, large shopping goods centers pull easily from 30 minutes and farther away.²⁵ Welch offers the example of Shopper's World, Framingham, where checks have shown that over 30 percent of the customers are coming from beyond a 30-minute travel-time zone.

Recent market surveys for large regional centers have considered areas corresponding to 45 minutes or even one hour driving time. The market potential in the fringe areas is usually heavily discounted.

Reilly's Law of Retail Gravitation

This method of analyzing retail trade areas was developed by William J. Reilly in 1929.²⁶ Reilly stated his law as follows:

Two cities attract retail trade, primarily shopping goods, from an intermediate city or town in the vicinity of the breaking point, approximately in direct proportion to the populations of the two cities and in the inverse proportion to the square of the distances from these two cities to the intermediate town.

Numerous applications of this theory have been made and tested by various researchers since it was proposed, with varying degrees

²⁴ Ibid, p. 12 of the original study.

²⁵ Welch, Kenneth C. "Factors in Planning Regional Shopping Centers." In Highway Research Board Bulletin 79, Washington, 1953.

²⁶ Reilly, William J., "The Law of Retail Gravitation," 2nd ed., Pilsbury Publishers, Inc. New York, 1953.

of success. In any particular application, the essential difficulty is the determination of the value of the distance exponent, which often appears to vary considerably from the value of 2 proposed by Reilly. Generally speaking, Reilly's adaptation of the basic theory of gravitation has been proved to give quite satisfactory results when realistically applied.

As commonly used in market analysis, certain modifications have been incorporated.²⁷ In place of population, some analysts have used retail floor area, area devoted to apparel, or actual G.A.F.²⁸ sales figures. Instead of actual roadway mileage, the time-distance has been used to compensate for unusual differences in traffic conditions on various parts of the highway network.

In place of the intermediate town used in Reilly's law, market analysts are generally concerned with the individual zones making up a market area. Such zones are usually defined so that each contains approximately the same number of families, and each is relatively homogenous as to economic character.

A useful adaptation of the retail gravitation principle was given by Harry J. Casey, Jr. in the *Traffic Quarterly* for July, 1955.²⁹ An excerpt from Casey's paper is as follows:

... recent developments in the use of the retail gravitation principle have adapted it for allocating to any number of 'towns' the purchases of any number of 'intermediate places.' By using this adaptation of Reilly's Law the purchasing power of each of the residential areas ('intermediate places') comprising the trading area of a city can be allocated, with reasonable accuracy, to each of the retail areas ('towns') in the city. This adaptation states that the purchases of the residents of a neighborhood (usually a census tract or group of tracts) are attracted to the retail centers in direct proportion to the size of the centers (expressed in square feet of retail area) and inversely as the squares of the driving time-distances from the neighborhood to the retail centers. This is expressed as:

$$B_{1,a} = \left[\frac{\frac{F_a}{(D_{1,a})^2}}{\frac{F_a}{(D_{1,a})^2} + \frac{F_b}{(D_{1,b})^2} + \frac{F_c}{(D_{1,c})^2} + \frac{F_d}{(D_{1,d})^2} \dots + \frac{F_z}{(D_{1,z})^2}} \right] \times B_1$$

²⁷ For a discussion, see Welch, Kenneth C., op. cit., p. 24.

²⁸ General merchandise, apparel, and furniture.

²⁹ Casey, Harry J., Jr. "Applications to Traffic Engineering of the Law of Retail Gravitation," *Traffic Quarterly*, July, 1955. The Eno Foundation, Saugatuck, Conn.

where B_1 is the buying power of neighborhood 1; $B_{1,a}$ the purchases made by the residents of neighborhood 1 in retail center A; F_a, F_b, F_c , etc., the square feet of retail space in the retail centers A, B, C, etc.; $D_{1,a}, D_{1,b}, D_{1,c}$, etc., the driving time-distances between neighborhood 1 and the retail centers.

He adds:

This method . . . is applicable only to the determination of how shopping goods purchases are allocated . . . Convenience goods typically are sold in the neighborhoods, and attract purchasers only for a distance of five or six minutes (in an urban area).

IV. The Off-Center Employment Area

Importance of Work Trips. A number of studies of urban travel patterns has shown that from a third to a half of all daily trips are made to and from work. The importance of these trips lies not only in their absolute and relative volumes, but also in the fact that the great majority of them are made during two well-defined periods of the day. They are the primary cause of the peak hour traffic flows which are an important consideration in street and highway planning.

The home-to-work travel patterns of today are quite different from those of fifty years ago, and they are rapidly changing with the changes in our city patterns.

Before the automobile attained importance as a means of personal transportation for the worker, work trips were made on foot, bicycle, or via public transportation. Most industrial concentrations were near the central business district, convenient to the hub of the transit system as well as the important carriers of raw materials and finished products.

The present mobility of the labor force and the development of truck transportation have resulted in relocation of many industrial enterprises. A recent contributing factor in many cities was the building of new factories for defense industries during World War II, and the housing developments which were located nearby. Many of the war-built factories in suburban and rural locations have been taken over by private industry.

Rising transportation costs, at least partly due to traffic con-

gestion in the central cities, has been a factor in the continuing relocation of industry. An example of industrial relocation to take advantage of modern highway facilities is found in the considerable amount of plant development along the route of the New York Thruway between Buffalo and New York City.

It is important that the highway and traffic planner be aware of changes taking place with regard to location of industrial plants. The importance of work travel in the overall traffic pattern of any community requires that the planner be able to evaluate the effects of such changes.

Relation of Home to Work Place. A reference has previously been made to a study of the relation of homes to work places by J. D. Carroll, Jr.³⁰ Carroll analyzed the distance from the place of work to the home of the worker, for industrial centers outside the CBD of four cities. Information from Carroll's study is shown in Table II-11. While the data which Carroll used represent conditions which have changed considerably, his study is nonetheless of value for comparative purposes. Carroll used the data to support his observation that off-center work places have employee residences concentrated in the nearby vicinity.

Table II-11
PERCENTAGE DISTRIBUTION OF WORKER RESIDENCES FROM PLACE OF WORK
(OTHER THAN CBD)

City and Date	Distribution by mile zones of:							
	0-1 mile	1-2 miles	2-3 miles	3-4 miles	4-5 miles	5-6 miles	6-7 miles	7 or over
Detroit, 1914	37.5	21.5	16.0	11.0	9.0	2.0		
Chicago, 1915	34.5	22.4	13.4	11.3	6.8	4.4	2.6	4.8
Pittsburgh, 1917	51.8	24.8	8.3	6.1	4.2	2.1	2.6 (6 &	
Milwaukee, 1927	22.7	32.1	19.6	16.0	9.6 (4 & over)			over)

SOURCE: J. Douglas Carroll, Jr. "The Relation of Homes to Work Places and the Spatial Pattern of Cities," *Social Forces*, Vol. 30, No. 3, 1952.

Study of the data shows that for the years studied, from one-quarter to one-half of the workers lived within a mile of the work

³⁰ Op. cit. p. 277.

Table II-12
 NUMBER AND PERCENTAGE OF NEWLY HIRED FACTORY WORKERS, BY DISTANCE BETWEEN RESIDENCE
 AND PLACE OF WORK AT TIME HIRED, FRANKLIN COUNTY, OHIO
 1940, 1943, 1947 AND 1950

<i>Distance</i>	<i>Number</i>				<i>Percentage Distribution</i>			
	<i>1940</i>	<i>1943</i>	<i>1947</i>	<i>1950</i>	<i>1940</i>	<i>1943</i>	<i>1947</i>	<i>1950</i>
Less than 1 mile	125	700	421	213	29.6	11.2	19.8	13.2
1-1.9 miles	81	573	313	220	19.2	9.2	14.7	13.7
2-3.9 miles	107	1,211	601	438	25.4	19.4	28.2	27.2
4-5.9 miles	65	1,523	285	239	15.4	24.3	13.4	14.9
6-7.9 miles	19	1,112	234	233	4.5	17.8	11.0	14.5
8-9.9 miles	4	394	96	108	.9	6.3	4.4	6.8
10-14.9 miles	8	231	62	66	1.9	3.7	2.9	4.1
15-19.9 miles	4	40	33	28	.9	.6	1.5	1.7
20-24.9 miles	2	94	36	21	.5	1.5	1.7	1.3
25-29.9 miles	2	83	29	16	.5	1.3	1.4	1.0
30 miles or more	5	296	21	26	1.2	4.7	1.0	1.6
Not reporting	19	307	138	92	—	—	—	—
TOTAL	441	6,564	2,269	1,700	100.0	100.0	100.0	100.0
Median Distance of those reporting	2.00	4.84	3.10	3.70	—	—	—	—

SOURCE: Adams, Leonard P., and Mackesey, Thomas W., "Commuting Patterns of Industrial Workers," Research Publication No. 1, Housing Research Center, Cornell University. Ithaca, January 1955.

place, and about 80 to 90 percent lived within a radius of four miles.

Additional information on this subject can be found in a recent publication by the Housing Research Center of Cornell University.³¹ Data included in the Cornell study are shown in Table II-12.

This table shows a trend from 1940 to 1950 toward fewer workers at the shorter commuting distances, relative stability at about five miles from the place of work, and general increases in the numbers of workers at longer commuting distances. This data may be somewhat misleading, however, as the information concerns only newly hired workers, and does not give a picture of the entire labor force. In a tight labor market, it would be natural that new workers would be recruited from increasingly greater distances.

Another analysis of commuting trends at a plant in upstate New York is shown in Table II-13, also from the Cornell study. This single example of a well-established plant shows a definite trend toward greater commuting distances. The effect of intensive recruitment of workers during the war years is seen to have persisted during the post-war period.

Table II-13

APPROXIMATE COMMUTING DISTANCES OF EMPLOYEES AT PLANT X
IN UPSTATE NEW YORK COMMUNITY
(Population of Area About 500,000)

Distance	Date							
	1921	1925	1930	1935	1940	1944*	1946	1951
	(Percent)							
0- 4.9	85.0	86.8	81.6	80.7	83.6	60.3	65.8	65.0
5-14.9	9.3	9.2	12.3	15.9	12.3	7.9	12.2	13.0
15-19.9	3.5	2.5	3.7	2.2	2.5	13.8	9.9	10.0
20-over	2.2	1.5	2.4	1.2	1.6	18.0	12.1	12.0

* Employment at the plant more than doubled between 1940 and 1944.

SOURCE: Adams and Mackesey. See note, Table II-12.

³¹ "Commuting Patterns of Industrial Workers," Leonard P. Adams and Thomas W. Mackesey. Research Publication No. 1, Housing Research Center, Cornell University. Ithaca, 1955.

The authors of that Cornell study caution against using these two examples as a basis for generalization:

In both illustrations it is significant that, in the post-war period with full employment, longer commuting distances from the pre-war ones have been maintained. These Ohio and upstate New York areas are probably not typical of all areas in which employment expanded rapidly during the war . . . They are presented not as a basis for broad generalizations, but only to show what was accomplished in particular instances where the plants were well known and attractive wages and conditions were offered.

Another section of the Cornell study by Adams and Mackesey compared 1951 travel distances of workers in plants in four areas of New York State. The results of this study are shown in Table II-14. As the authors point out, there is not complete uniformity in distance patterns for workers at different plants within the same area. In the Capital District the percentage of workers living within five miles of their places of employment ranged from 7.7 percent to 86.6 percent, and those who lived twenty or more miles away varied from 0.4 percent to 21.5 percent.

The Binghamton area showed greater uniformity, where in most instances about 90 percent of the workers studied lived within ten miles of their work places and those traveling twenty miles or more did not exceed about 2.0 percent.

There did not appear to be any particular relationship between size of plant and the pattern of distances traveled by the workers, either in the individual districts or in all plants studied irrespective of district.

Adams and Mackesey suggest that the main factors that explain commuting distances are the following:

1. Location of the plant relative to the densely populated sections of an area.
2. The amount, speed of growth, and probable permanency of job openings.
3. Company policies with respect to hiring and employee housing.
4. Alternative work opportunities.

Table II-14

DISTANCES TRAVELED BY PRODUCTION WORKERS
FALL 1951

Distances Traveled (Miles)	Plants Ranked from Largest to Smallest — % of Production Workers									Area Average
	1	2	3	4	5	6	7	8	9	
Capital District*										
0- 4	55.0	58.7	86.6	76.3	66.7	52.4	60.8	7.7	37.5	56.9
5- 9	17.0	22.7	7.8	11.4	15.8	2.4	32.2	45.4	5.9	17.0
10-14	6.0	6.8	3.7	6.8	8.7	12.2	3.2	23.4	35.4	7.1
15-19	10.0	3.1	1.5	4.0	4.2	11.5	2.5	3.1	4.6	8.2
20-over	12.0	8.7	0.4	1.5	4.6	21.5	1.3	20.4	16.6	10.8
Binghamton**										
0- 4	77.5	77.4	84.7	78.9	80.8	(-)	85.1	81.9	85.6	79.4
5- 9	13.3	12.9	9.9	15.9	12.0	(61.1)	8.4	7.7	8.4	12.3
10-14	4.8	5.1	2.4	4.3	3.2	(-)	2.6	8.3	4.8	4.4
15-19	2.4	2.6	1.5	—	1.8	(37.2)	1.8	0.6	0.6	2.0
20-over	2.0	2.0	1.5	0.9	2.2	0.7	2.1	1.5	0.6	1.9
Elmira										
0- 4	74.3	72.0	90.0	73.0	77.4					77.4
5- 9	10.2	10.0	1.9	10.0	10.5					10.5
10-14	2.3	7.0	3.9	3.0	3.3					3.3
15-19	9.1	7.0	1.2	11.0	5.7					5.7
20-over	4.1	4.0	3.0	3.0	3.0					3.0
Sidney, Owego, Norwich										
0- 4	45.5	76.2	53.9							
5- 9	8.0	9.9	22.6							
10-14	11.7	10.1	6.7							
15-19	23.0	2.0	6.3							
20-over	11.8	1.8	10.5							

* Albany, Schenectady, Troy.

** Several plants of one large concern are listed separately.

SOURCE: Adams and Mackesey. See note, Table II-12.

The authors conclude that, generally speaking, workers are now traveling much farther to work than they used to, probably more so in small industrial areas than in large cities. Private ownership of cars has freed workers to live in suburban or rural areas in accordance with their wishes. They are able to obtain new jobs when unemployed, or switch to better-paying jobs, without the necessity of changing place of residence.

The study found that two-thirds to three-quarters of the workers live within fifteen to twenty miles of their work places in most areas. In some areas, over 90 percent live within twenty miles.

Measured in time, the study found that very few will spend more than an hour and a half each way in traveling to work in the summer, and an additional fifteen to thirty minutes in the winter.

The areas from which workers are drawn are not limited to urban and suburban places. In some parts of the Northeast, according to the study, two-thirds to three-quarters or more of the residents of rural areas make their living at non-farm work, and only a small percentage of these workers attempts to farm on a part-time basis.

In estimating travel patterns to a proposed new industry in or near a poor farming area, the authors of the Cornell report suggest that many marginal farmers and others in low-paying jobs in country or village stores would be likely candidates for good job opportunities.

Turning to the relation between place of work and residence of government employees in Washington, D. C., this subject was investigated by the Bureau of Public Roads, Department of Commerce, in 1954. One chart developed for this unpublished study is shown in Figure II-22.

The upper part of this figure includes a curve of population distribution throughout the various sectors of the metropolitan area. A comparison of this curve with the distribution of centralized agency employees shows that these employees are geographically distributed very much as the total population of the area.

In contrast, the curves of the lower part of Figure II-22, for

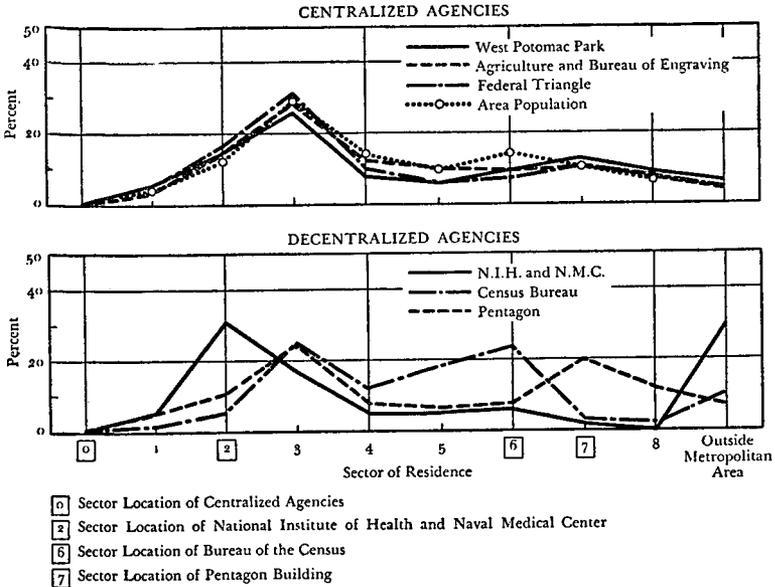


FIGURE II-22. Geographic sectors of residence of employees making work trips to selected government agencies, centralized versus decentralized, Washington, D. C. metropolitan area, 1948.

SOURCE: Unpublished study by Bureau of Public Roads.

the decentralized agencies, shows marked residence concentrations in the vicinity of the individual work places. Sector 3, including about 30 percent of the area population, is also shown to be an important source of workers. These findings generally parallel those of Carroll.

A study of the driving time from residences of workers to these same employment centers is shown in Figure II-23. As this figure shows, about 50 percent of the workers at the centralized agencies lived within an area that could be reached in less than 15 minutes, and 90 percent lived less than 25 minutes from work. At the decentralized agencies, workers were distributed at somewhat greater distances. Fifty percent lived within a 20-minute radius from work, while about 20 percent of the workers at two of the three agencies lived at 30 minutes or more driving time from their place of employment.

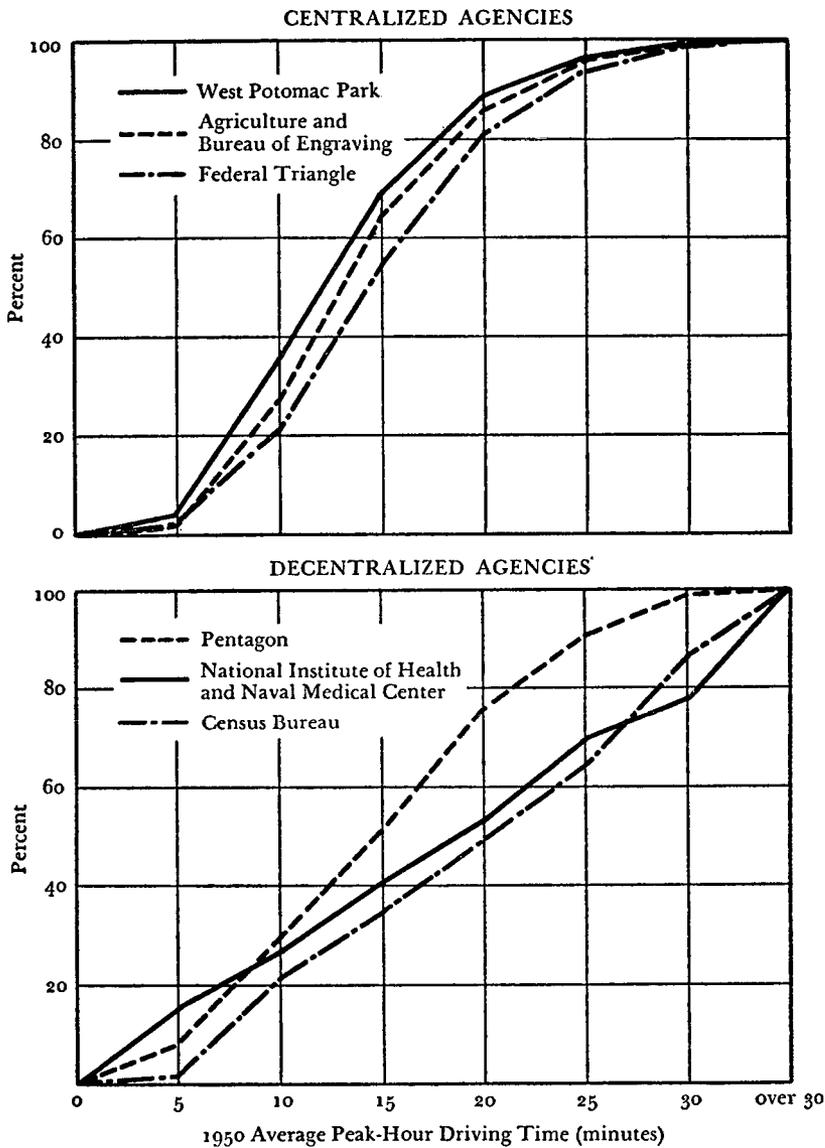
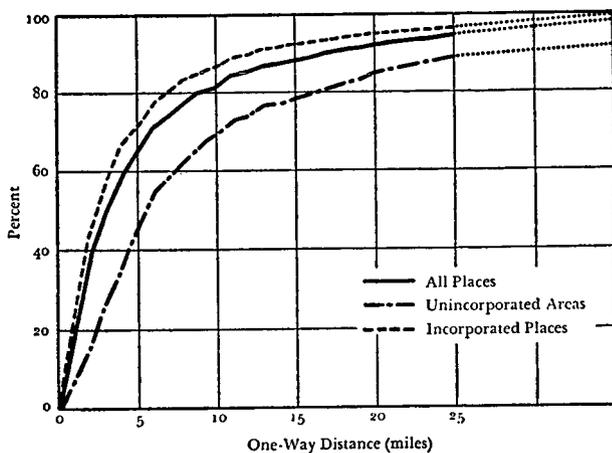


FIGURE II-23. Residence locations of employees making work trips to selected government agencies, by cumulative average peak-hour driving time areas, centralized agencies versus decentralized agencies, Washington, D. C. metropolitan area, 1948 (internal only).

Source: Unpublished study by Bureau of Public Roads.

CUMULATIVE DISTRIBUTION



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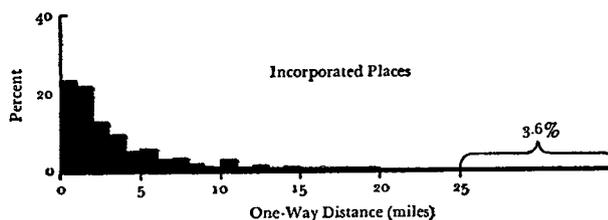
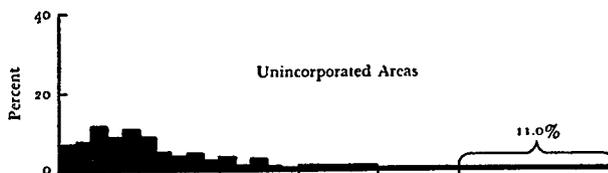
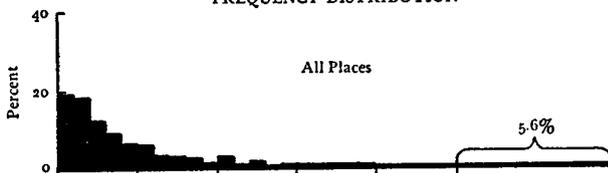
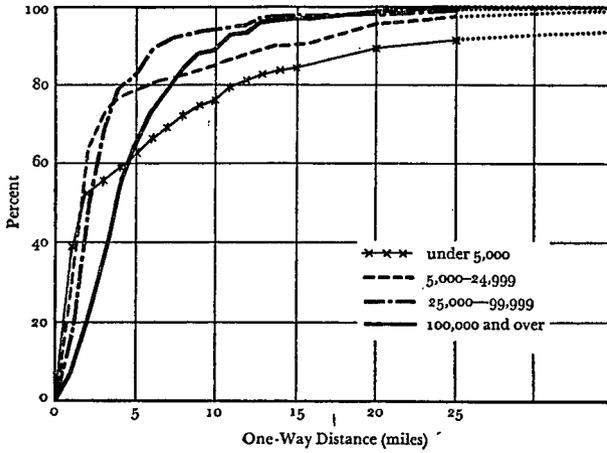


FIGURE II-24. Gainfully-employed workers using passenger cars for home-to-work travel, classified by distance to place of employment and by place of residence; summer of 1951, six states.

SOURCE: *Public Roads*, Vol. 28, No. 5, December, 1954.

CUMULATIVE DISTRIBUTION



FREQUENCY DISTRIBUTION

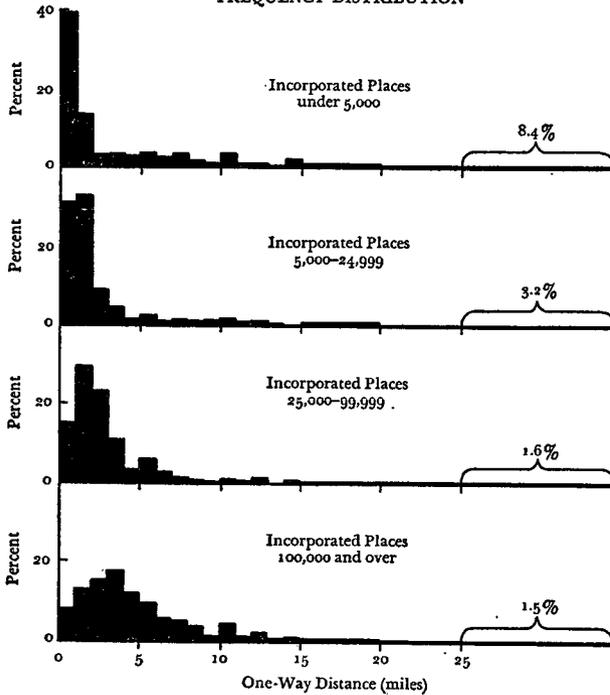


FIGURE II-24. Gainfully-employed workers using passenger cars for home-to-work travel, classified by distance to place of employment and by place of residence; summer of 1951, six states.

SOURCE: *Public Roads*, Vol. 28, No. 5, December, 1954.

An analysis of travel to and from work appeared in the December, 1954 issue of *Public Roads*,³² as part of the report on a motor vehicle use study in six states. Distances traveled by workers who used passenger cars for home-to-work travel in incorporated places are shown in Figure II-24. This group of workers represents about 62 to 64 percent of all workers requiring home-to-work travel in incorporated places having populations under 100,000, and 46 percent of such workers in larger cities.

In commenting on this distribution of travel distances, the authors point out that the percent of workers traveling more than twenty-five miles from home to work is greatest among those who live in the smallest cities, and that this percentage drops with increase in city size. Also, while 60 to 80 percent of the workers living in all the cities traveled five miles or less to work, the number traveling the shorter distances (one and two miles) decreased markedly with increase in city size. Two factors that

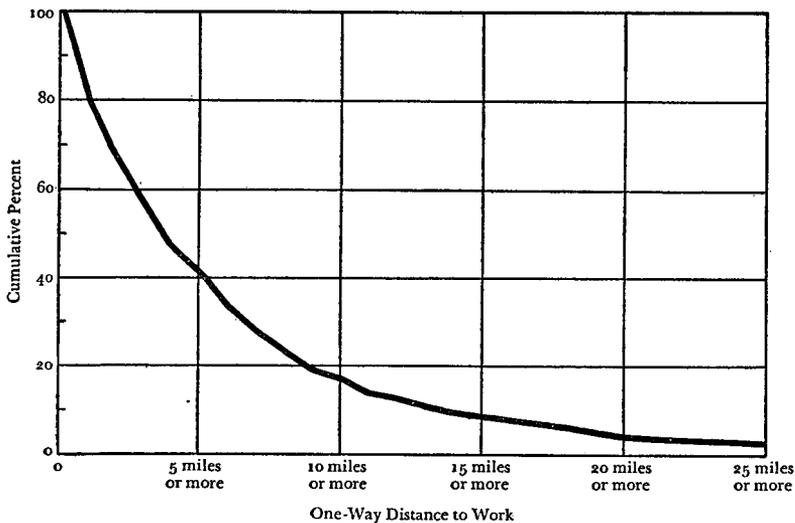


FIGURE II-25. Cumulative percentage distribution of Missouri gainfully-employed persons (excluding those gainfully employed at home). Classified by the minimum one-way distance to their work during year 1951-52.

SOURCE: Missouri State Highway Department.

³² *Public Roads*, Vol. 28, No. 5, December 1954. "Motor Vehicle Use Studies in Six States," Bureau of Public Roads, Division of Research.

could account for this are the greater spacial separation of industrial and residential areas and greater use of public transportation for short travel distances in the larger cities.

A similar state-wide study in Missouri³³ produced the curve of Figure II-25, which indicates that about 60 percent of the workers in the state live within five miles of their employment, and only about 4 percent travel twenty miles or more.

Mode of Travel to Work. The *Public Roads* report also included an analysis of the mode of travel used by workers in the various population groups. As shown in Figure II-26, the use of the private automobile was greatest in unincorporated places, fairly constant at a lower level in cities up to 100,000 population, and lowest in cities of over 100,000. The percent of workers who

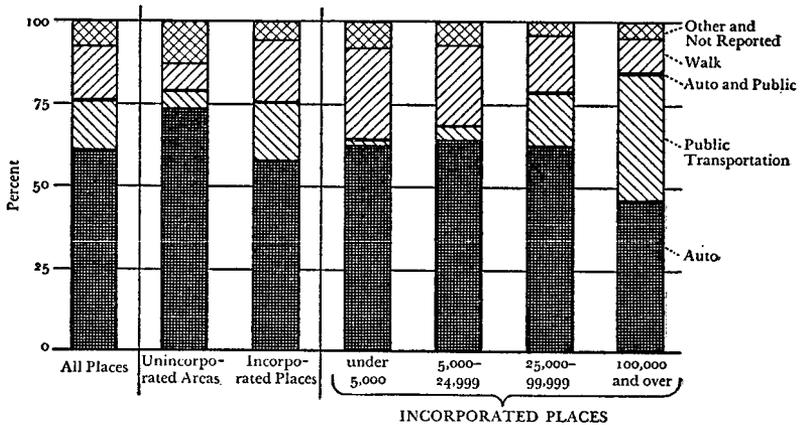


FIGURE II-26. Gainfully-employed workers in each population group using various modes of home-to-work travel; summer of 1951, six states.

SOURCE: *Public Roads*, Vol. 28, No. 5, December, 1954.

walked from home to work was found to be an important consideration in the small and medium-sized cities, a matter which has not been commonly investigated. As might be expected, the use of public transportation was greatest in the large cities, and appears to be relatively insignificant in unincorporated places and in cities below 25,000 population.

³³ "A Motor Vehicle Use Survey of Missouri, 1951-1952." Missouri State Highway Department and Bureau of Public Roads.

The unpublished study by the Bureau of Public Roads of work travel by government employees also included some data on mode of travel in the Washington, D. C. area. No account was taken of walking trips. From the study just discussed, however, we can assume such trips to be unimportant in a city of this size.

The pattern disclosed by Figure II-27 is not unexpected. The majority of workers at the centralized agencies used mass transit in going to and from work. Auto travel was of major importance at the decentralized agencies, although there was considerable variation in the amount of mass transit usage at the three places studied. Special transit service for these large government agencies is undoubtedly an important factor.

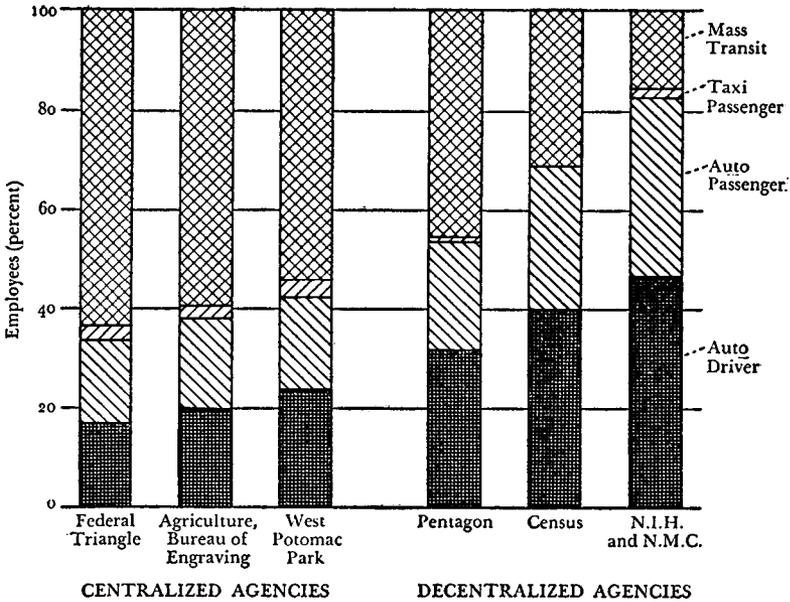


FIGURE II-27. Comparison of the mode of travel of employees work trips to selected centralized and decentralized government centers, Washington, D. C. metropolitan area, 1948.

SOURCE: Unpublished study by Bureau of Public Roads.

Estimating Work-Trip Volumes. A suggested method of estimating work-trip volumes to a particular plant or industrial

area was developed in a 1952 student thesis by Alan M. Voorhees at the Bureau of Highway Traffic, Yale University.

This method is based on a study of work travel in a small sample of cities. It is concerned only with auto and transit trips and ignores walking trips. The method is based on empirical data which indicated that in the areas studied, work trips were generated at the maximum rate from a distance of one and three-quarter miles from the individual plants. From the area within this radius, walking trips were assumed to be the primary factor in reducing the rate of trip generation. Beyond this point of maximum work-trip generation, the rate dropped off exponentially.

The rate of work-trip generation was expressed as a "work-trip ratio," defined as the average number of trips performed by each member of the labor force.

Other definitions used by Voorhees are:

1. The "average work-trip ratio" for a particular employer is the ratio of all work trips generated by the plant to the total labor force in the urban area.
2. The "maximum work-trip ratio" for a particular employer is the highest rate of travel per resident worker found in any residential zone.

A standardized curve of variation in work-trip ratios based on distance from the subject plant is illustrated in Figure II-28. Voorhees describes this curve as typical for both all modes of travel and for auto driver trips. The curve for transit trips varies from this curve in that from the point of maximum rate of trip generation, the curve is a straight line sloping downward to the right to a value of zero at the distance corresponding to the outer limits of the transit system.

Voorhees' outline of his basic procedure is as follows:

"1. The urban area must be subdivided into tracts of convenient size. The census tracts offer many advantages. The number of workers (labor force) in each tract must be determined from census data or by approximation. The number of employees in the industrial area must also be established, and the percentage who travel to work by different modes must be obtained. If the study is being made to anticipate effects of an employer who does not yet exist, these values must, of course, be approximated.

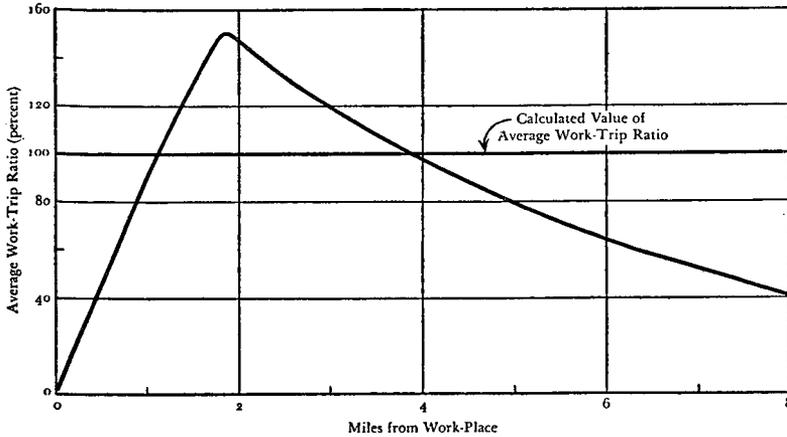


FIGURE II-28. Standardized curve of work-trip generation.

SOURCE: Developed by A. M. Voorhees at the Bureau of Highway Traffic, Yale University.

2. Shapes of the curves for work-trip ratios may be determined by using the following formulas:

1. Trips by all modes of travel:

$$\log Y = -\frac{.32 X}{M}$$

2. Trips by auto drivers:

$$\log Y = -\frac{.35 X}{M}$$

where X = number of miles from industrial plant

M = average length of work trip in miles

Y = relative value of the work-trip ratio

Values for M must be estimated. The formulas provide the portions of curves beyond $1\frac{3}{4}$ miles. A straight line should be drawn from the XY intersect to this point. Transit-trip generation can be anticipated by drawing a straight line from the maximum work-trip ratio at $1\frac{3}{4}$ miles to zero trip generation at a point on the distance scale which represents the limits of the transit system. A straight line should also be drawn from the XY intersect to the point representing maximum work-trip ratio for transit riders.

3. The preceding steps construct the shapes of the curves. Absolute values can be determined by estimating the maximum value of the work-trip ratio (probably about 50 percent larger than the assumed average ratio). This will determine absolute values on the vertical scale by means of which theoretical trip generation in each residential zone can be found. Theoretical trips should be totaled, compared with the known volume of trips, and a

flat percentage correction made to bring the theoretical total into agreement. The same correction applied to the scale of work-trip ratios will establish correct values on it."

This theory has been further developed by F. H. Wynn while a research assistant at the Yale Bureau. Wynn states that a somewhat improved estimate of the true worker distribution pattern is obtained by first distributing the workers according to Voorhees' method, and then repeating the process in the reverse direction. That is, the known or estimated volume of workers in the residential areas are distributed to the major work areas by use of the curve of Figure II-28. The two estimates are then averaged by a process of successive approximations.³⁴

Recent work by Voorhees has indicated that work trips can more adequately be predicted by using a modified concept of Reilly's Law of retail gravitation. In applying this principle to work trips it was found that the size of the employment area should be expressed as the number of workers employed, and the distance factor as a square root function rather than a squared function. This procedure takes into consideration the competition between employment centers in metropolitan areas, something that is not provided in his original procedure.

He suggests that in the larger cities it may be necessary to divide work trips into several categories, such as white-collar workers, industrial, and retail. This concept is further explored in a paper prepared by Voorhees in 1955.³⁵

V. The City As A Generator

External-Local Traffic

Some planning activities may require consideration of an entire city as a unit generator of highway traffic. In this sense the incorporated city with its built-up environs is considered as the magnetic attractor of traffic from a more extended area which may include one or more counties.

³⁴ See Fratar, Thomas J., "Vehicular Trip Distributions by Successive Approximations," *Traffic Quarterly*, January, 1954. The Eno Foundation.

³⁵ *A General Theory of Traffic Movement*, Alan W. Voorhees. 1955 Past Presidents' Award Paper, Institute of Traffic Engineers. Institute of Traffic Engineers, 1956.

In terms used in the standard origin and destination traffic survey, this movement corresponds to the "external-local" interchange of traffic.

A brief investigation of such traffic movements, as they are related to population, was made by the authors.

The hypothesis of the study was that the number of trips between two distinct areas is in some way proportional to the product of the populations of the two areas. This hypothesis has been used by a number of researchers,³⁶ and normally includes an inverse proportionality to some power of the distance between the two areas.

As used in this investigation, one area was the internal area of the origin and destination traffic surveys from which trip data were obtained. The other was the surrounding area, herein called the "external area," out to the limits of the metropolitan area as defined by the U. S. Bureau of the Census.³⁷

The total population of the metropolitan area was adjusted to the year of the traffic study, as shown in Column 1, Table II-15. The population of the internal area, as given in the traffic survey reports, was then deducted to give the population of the external area.

This so-called external area population is a misnomer, as the external area properly should be considered of unlimited size. Traffic studies have shown, however, that the great bulk of daily traffic entering a city comes from the immediately surrounding area, and that long-distance travel constitutes but a small proportion of the daily traffic movement. It was also believed that the error introduced by the above assumption would be relatively constant for all cities studied, and would not seriously affect the results.

The distance factor (D) in the basic formula $P_1 \times P_2 / D^x$ would be relatively constant in comparing one city with another, and it was not considered in the calculations.

³⁶ For a discussion of several studies, see Iklé, Fred Charles, "Sociological Relationship of Traffic to Population and Distance," *Traffic Quarterly*, Vol. VIII, No. 2, April, 1954. The Eno Foundation, Saugatuck, Conn.

³⁷ The reader is cautioned not to confuse the two areas, as most traffic surveys also define the internal area as the metropolitan area. In every case used in this study, the "external area" included one or more complete counties.

The idea tested, therefore, was simply that external-local traffic volumes are proportional to the product of the external and internal populations.

Calculations for nineteen cities of various sizes are shown in Table II-15. The values obtained for the products of the populations P_i and P_e are shown in Column 4, and the actual volumes of one-way (inbound) external-local auto trips are shown in Column 5.

When the actual trip volumes are plotted against the $P_i P_e$ values, as in Figure II-29, a fairly smooth curve can be drawn. The curve suggests that actual trip volumes increase, but at a decreasing rate, as the population product increases. Also, a maximum value of about 50,000 local-external auto trips per day was indicated by the cities used in the study.

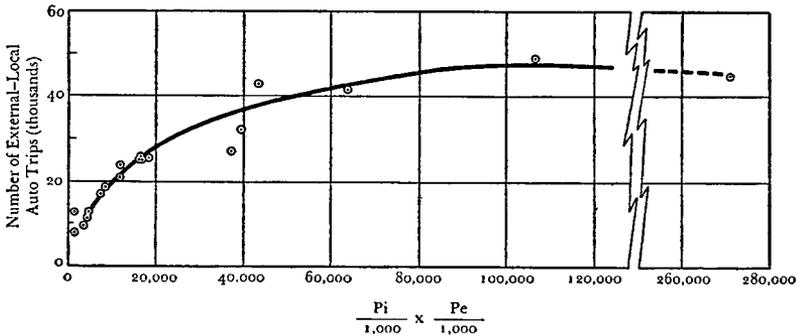


FIGURE II-29. Actual number of external-local trips vs. theoretical number of trips.

The ratios of actual trips to the population products, $P_i P_e$, are also given in Table II-15, column 6, and these values are plotted against the Census Bureau's "metropolitan area" population figures in Figure II-30.

As the curve of Figure II-30 indicates, actual trip values in the smallest cities are about ten times the value suggested by the population product theory, while in the largest cities the actual trip values are only a fraction of the suggested values. The extreme values shown in the table indicate that the rate of generation of external-local trips in the smallest city was in the order of

Table II-15

COMPARISON OF EXTERNAL-LOCAL TRAFFIC WITH POPULATION PRODUCT THEORY

City	Metro. Area Pop. ¹ (1)	Internal Area Pop. (P _i) (2)	External Area Pop. (P _e) ² (3)	$\frac{P_i}{1000} \times \frac{P_e}{1000}$ (4)	No. of Auto Trips Exter- nal-Local (5)	Ratio, ³ Actual to Population Product (6)
Baltimore 1945	1,210,000	912,800	297,200	271,000	44,308	0.16
Houston 1953	1,000,000	878,600	121,400	106,600	48,875	0.46
Seattle 1946	641,000	518,600	122,400	63,500	41,400	0.65
Dallas 1950	614,800	533,600	81,200	43,300	42,703	0.99
Indianapolis 1945	507,000	411,600	95,400	39,300	32,005	0.81
Norfolk 1950	446,200	335,900	110,300	37,100	27,026	0.73
Grand Rapids 1953	303,000	221,000	82,000	18,100	25,631	1.42
Tacoma 1948	257,000	138,700	118,300	16,400	25,007	1.53
Salt Lake City 1947	256,000	196,600	59,400	11,700	20,820	1.78
Reading 1949	254,500	119,900	134,600	16,100	25,369	1.58
Scranton 1951	253,500	137,100	116,400	16,000	24,720	1.54
Erie 1950	219,400	128,600	90,800	11,700	23,837	2.04
South Bend 1946	188,000	119,400	68,600	8,200	18,456	2.25
Madison 1951	174,500	104,100	70,400	7,300	17,038	2.34
Saginaw 1948	149,000	112,900	36,100	4,070	11,477	2.82
Albuquerque 1950	145,700	116,100	29,600	3,440	9,236	2.69
Altoona 1952	139,400	85,300	54,100	4,600	12,890	2.80
Bay City 1948	85,800	69,200	16,600	1,150	7,934	6.89
Kenosha 1952	78,000	55,800	22,200	1,240	12,567	10.13

¹ From U. S. Census. Adjusted to year of traffic survey by straight line trend, 1940-1950.

² Col. (1) minus Col. (2).

³ Col. (5) divided by Col. (4).

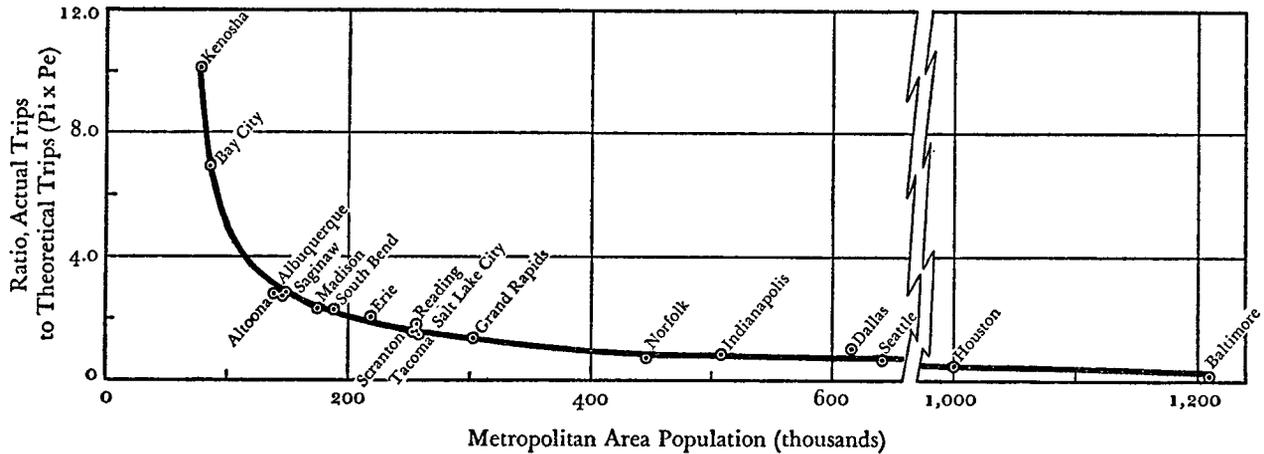


FIGURE II-30. Ratio of actual to theoretical number of external-local trips vs. population of metropolitan area.

fifty times greater than that found in the largest city. This assumes, of course, that the generation should in fact be proportional to the population product.

While this study should be considered as preliminary in nature, it strongly suggests that the P_1P_2/D^x theory must be modified in application by more than an exponential correction for D. Variations in distance would hardly account for the rather uniform variation in the ratios shown in Figure II-30.

One obvious reason for greater relative trip generation in the smaller cities is the greater local importance of the central business districts in such cities. Many other factors might be investigated in a more detailed study.

By-Passable Traffic

The proportion of the traffic approaching a city which is destined for the city itself, or conversely, the proportion which would like to by-pass the city, is a function of city size.

As cities increase in size, a greater proportion of approaching traffic has a destination within the city. This is a general rule, however, and considerable variation may be found between

Table II-16
 PROPORTIONS OF TRAFFIC BOUND TO AND BEYOND CITIES
 OF VARIOUS POPULATIONS

<i>Population Group</i>	<i>No. of cities</i>	<i>Traffic bound to the city (percent)</i>	<i>Traffic bound beyond the city (percent)</i>
Less than 2,500	6	49.3	50.7
2,500 to 10,000	6	56.7	43.3
10,000 to 25,000	3	78.1	21.9
25,000 to 50,000	5	79.0	21.0
50,000 to 100,000	2	83.8	16.2
100,000 to 300,000	2	81.6	18.4
300,000 to 500,000	2	92.8	7.2
500,000 to 1,000,000	1	95.8	4.2

SOURCE: *Interregional Highways*, House Document 379, Report of the National Interregional Highway Committee, U. S. Govt. Printing Office, Washington, 1944. From origin-destination surveys on highways approaching 27 cities.

cities of approximately the same size. Table II-16 is indicative of average values found in a study of twenty-seven cities.

It has been found that the location of a city with regard to other cities is important in explaining variations from the average.

A small city located near a large city will be the origin or destination of a smaller than average percentage of the traffic in the area. A city of the same size which dominates the surrounding territory will be the focal point of traffic movements, and the amount of by-passable traffic will be relatively low.

Caution must be exercised in applying average percentages to the individual highways approaching any city.

The proportion of through-traffic logically will be higher on major inter-state routes than on secondary state highways or county roads. In this connection J. Carl McMonagle of the Michigan State Highway Department has said, "Our studies have indicated that traffic wishing to bypass a single city on the several trunkline routes may vary percentage-wise from 8 to 60 percent."

Inter-Area Travel Formulas

Attempts to develop travel formulas are not new. As early as 1889 an Austrian scientist, Eduard Lill,³⁸ proposed a law of travel expressed as $xy = M$. The symbol M , a constant, represents the travel value of a particular place, while y represents the number of travelers going to *or beyond* a place located at a distance x from the starting point. Attempts to apply Lill's formula to specific situations have not been too successful. In commenting on this, Torsten R. Astrom³⁹ says:

—the discrepancy between Lill's theoretical law of traffic and the results of practical experience is to be regarded as quite natural. The reason is that Lill has established a general law which holds good for all kinds of journeys, irrespective of the type of means of transportation, and that this law cannot be applied directly to a definite, limited means of transportation.

³⁸ Discussed in the paper "Laws of Traffic and their Applications to Traffic Forecasts with Special Reference to the Sound Bridge Project," Torsten R. Astrom, Royal Institute of Technology, Stockholm, 1953.

³⁹ *Ibid.*

Astrom also quotes from a paper published in 1930 by another Swedish investigator, H. N. Pallin, who said:

The many-sided and remarkable ability of human communities to attract traffic from their surroundings seems to comply, within readily discernible approximate limits, with the general theoretical law stating that the attraction varies directly as the relative 'mass' of the community and inversely as the distance from the center of gravity of the community raised to a power which approaches and is theoretically in all probability equal to, the square. There are good reasons to believe that this phenomenon of attraction, considered within its psychological frame, is similar to general gravitation, although it is liable to disturbances—largely influenced by wide differences between technically imperfect and attenuating local structures of urban areas—which are so numerous and intricate that the effects of attraction can be reduced, and can also be subjected to wide variations from one individual case to another. It seems that this phenomenon may possibly be regarded as a human parallel to those which constitute the subjects of Newton's and Coulomb's laws. The simplest, though evidently approximate, method of solving the problem of the 'mass' met with in this connection is to assume that this 'mass' corresponds to the number of individuals—or rather to the number of individual wills. The uncertainty of this method of calculation is so obvious that it need not be stressed.

The formula suggested by Pallin has been used, with some modifications, by many students of the problem. The formula is usually expressed simply as

$$V = k \frac{P_1 \cdot P_2}{D^x}$$

where

- V is the number of trips (or persons or vehicles)
- P₁ is the population (or vehicle registration) of area 1
- P₂ is the same for area 2
- D is the distance between areas 1 and 2
- x is some power of D, usually 2
- k is a constant used to adjust the different dimensions involved in the formula

Numerous difficulties have been encountered in testing the formula with known highway traffic data. Such difficulties are not surprising, considering the many factors involved. For example, the mode of transportation is a variable that must be considered when calculating travel between any two areas. Even when motor vehicle registration is used for the "P" factor in estimating auto travel, the formula makes no allowances for alternate choice of transportation at various distances.

Other influences which tend to deny universal application of the basic formula are found in economic, cultural, political, and topographic factors which modify the traffic potential of any area. Perhaps the greatest difficulty of all is the lack of reliable statistical data on all forms of travel which has restricted the extent of research.

Most researchers to date have attempted to modify the basic formula so as to approximate known travel volumes. Usually this modification has taken the form of altering the power of D to something other than 2. In the paper previously quoted, Astrom makes the suggestion:

“It appears fundamentally advisable to use the general law of traffic as a primary point of departure in calculating the total amount of traffic, and then use this amount as a basis for determining the volumes of traffic handled by the individual means of conveyance.”

Iklé⁴⁰ has reported testing the formula with data on automobile trips between the CBD and other districts in Dallas, where he found a value for x of 0.689. For automobile trips between Fort Wayne (or passing Fort Wayne) and counties in Indiana, x was as high as 2.57. A test of intercity travel data from the state of Washington gave a value for x of 2.6. For airline trips between twenty-nine major U. S. cities, x was found to be 1.07.

J. D. Carroll, Jr. has reported⁴¹ on a study of intercity auto travel in Michigan, using data from a state-wide survey by the Planning and Traffic Division, Michigan State Highway Department.⁴² Cities were grouped in various classifications ranging from “neighborhood center” to “regional center.” The effect of distance on trip volumes to these centers was indicated by values for the distance exponent ranging from 2.83 to 3.36. Trips to Detroit from one hundred places within a three hundred mile radius were studied by Carroll, resulting in a distance exponent

⁴⁰ op. cit.

⁴¹ Carroll, J. D., Jr., “Defining Urban Trade Areas,” *Traffic Quarterly*, Vol. IX, No. 2, April, 1955.

⁴² See also “A Method of Rural Road Classification,” reprint of a report submitted to the Annual Meeting of the Highway Research Board by J. Carl McMonagle, Planning and Traffic Division, Michigan State Highway Department, January 1950.

of 2.98. Carroll therefore suggests that travel varies more nearly with the cube of the distance than with the square of the distance.

In a letter dated August, 1954, Astrom⁴³ expresses a similar thought:

Continued investigations at the Division of Traffic and Transport Engineering (Royal Institute of Technology, Stockholm, —Ed.) have indicated that the motor traffic is changing related to distance with a power higher than 2. Revisions of material from the Chesapeake Bay Bridge indicate the power of 3, and destination investigations of a number of Swedish roads indicate the power of 2.7.

W. R. Bellis, Chief, Traffic Design and Research, New Jersey State Highway Department, has developed a formula for computing inter-area traffic volumes in that state.⁴⁴ Bellis uses the following basic formula to express the traffic volume moving from one area to another:

$$V = \frac{R_1 f_2}{T^2} \quad (1)$$

where: V = the volume of traffic from area 1 to area 2
 R_1 = the number of motor vehicles registered in area 1
 f_2 = the force of attraction which area 2 exerts on area 1
 T = the total elapsed time to travel from area 1 to area 2

In order to account for return trips, the above expression must be multiplied by two. A similar expression is used to represent the round trips originating in area 2, and attracted to area 1.

The total traffic volume between the two areas is therefore expressed as:

$$V = \frac{2 R_1 f_2}{T^2} + \frac{2 R_2 f_1}{T^2} \quad (2)$$

The attractive force, f , exerted by an area is $f = .001 R \frac{R}{P} F$,

where: .001 = a constant determined by experiment when V = annual average daily traffic and T is expressed in minutes
 P = the population of the area
 F = an attractive force in addition to the normal attraction

⁴³ op. cit.

⁴⁴ Discussion taken from an unpublished paper by Bellis, written in 1954.

By substituting the above expression for f in formula (2), the following formula results:

$$V = \frac{R_1 R_2}{T^2} \left(.002 \frac{R_1}{P_1} F_1 + .002 \frac{R_2}{P_2} F_2 \right) \quad (3)$$

The value of T is the total elapsed time of travel, in minutes, including any overnight stops.

Bellis makes an interesting point with regard to this formula. When a level of stabilization is reached in vehicle registration (which he assumes as $P/R = 2$), substitution of this value in the above formula will produce the following:

$$V = \frac{R_1 R_2}{1000 T^2} (F_1 + F_2)$$

which is the general law of travel previously discussed, with the addition of the special attraction factors F_1 and F_2 .

It seems reasonable to assume that some such factors are necessary, and that there is scant hope for a universal travel formula that does not contain them.

Bellis discusses the value of F as follows:

For most areas $F = 1$, but for recreational areas or highly industrialized areas F is greater than 1. It is also found to be less than 1 for some areas.

At the present time the value of F is found by experiment, comparing the calculated volumes with the observed volumes at strategic locations.

In illustrating values of F assigned to some of the Atlantic beach areas relative to the larger cities, Bellis states that the area just south of the Raritan River has been found to have an attraction factor of 5 for the Newark area, while Newark residents are attracted to the Asbury Park area by a factor of 10 and to the Point Pleasant area by a factor of 15. These beach areas do not have the same attraction factors for other areas, such as Paterson or Plainfield. The Atlantic City area has been found to attract the Newark area with a factor of 5, but the Philadelphia area with a factor of 50.

As an illustration of areas having F factors of less than 1, Bellis cites the attractions between northern New Jersey and Connecti-

cut, where New York City and the Hudson River act as barriers in discouraging the free flow of traffic.

Mrs. Willa Mylroie, Research Assistant Professor in the Department of Civil Engineering, University of Washington, and Executive Secretary, Washington State Council for Highway Research, has developed a formula to express "intercity travel desire." The formula is expressed as

$$F = \frac{\sqrt{P_1 \cdot P_2}}{D^2}$$

where F is the intercity travel desire factor, and the other factors are the population and distance values as used previously

After computing the value of F for any pair of cities, Mrs. Mylroie found that intercity traffic volumes in Washington State could be closely approximated through use of the formula

$$y = 239 x^{0.59}$$

where y = average daily traffic (total for both directions),
and x = F, the travel desire factor

In order to estimate the total traffic on the highway between any two cities, the above formulas are used to compute the values of ΣF and $y = 239(\Sigma F)^{0.59}$ for all appropriate pairs of cities, including those located as far as 300 miles on each side of the two under consideration.

The expression for the conversion factor, y, as determined for the state of Washington, may not be applicable to other states or areas. The method of determining this expression for any other area is described by Mrs. Mylroie as follows:

1. Determine major through-routes of the state or use all intercity routes.
2. Compute total travel desire factor for each section of each route using all the cities on the routes chosen.
3. Determine minimum traffic on each section of the routes (or use origin and destination data if available for all routes).
4. Plot the minimum traffic of each route section against the corresponding travel desire factor on log-log paper.
5. If plot shows a linear trend on log-log paper, compute a regression line equation.
6. Convert equation to exponential form.

The regression line equation is computed from the following simultaneous equations:

$$\begin{aligned}\sum \log y &= n \log a + b \sum \log x \\ \sum \log x \cdot \log y &= \log a \sum \log x + b (\log x)^2\end{aligned}$$

For the state of Washington, the regression line equation is:

$$\log y = 2.3774 + 0.5877 \log x$$

Converted to exponential terms,

$$y = 239 x^{0.59}$$

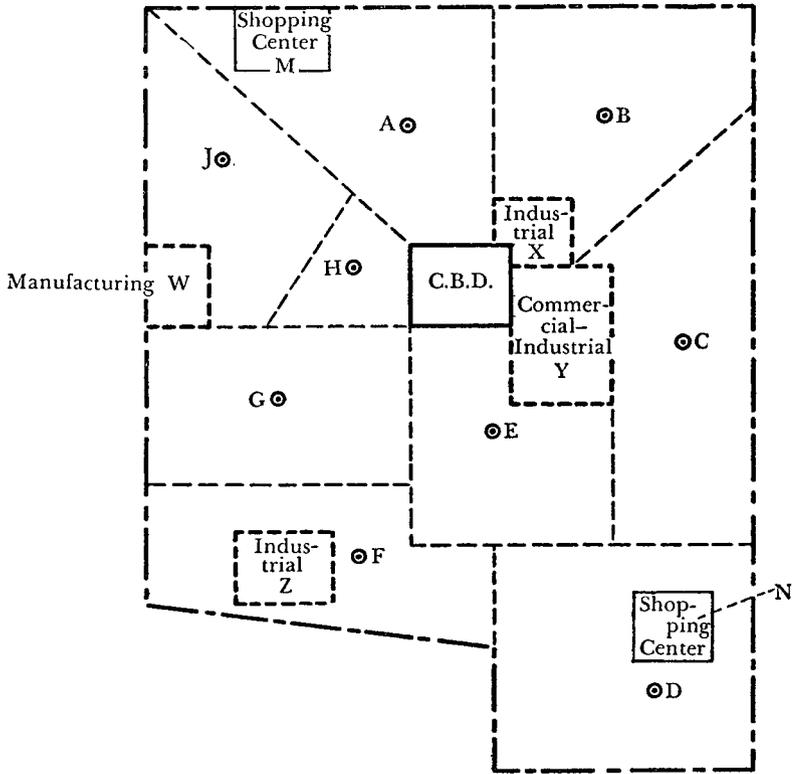
VI. Estimating Urban Traffic Patterns

The numerous studies quoted and discussed in this chapter can be used to make partial estimates of traffic flow patterns. Extreme accuracy cannot be expected, and the lack of information on some aspects of the total travel pattern leaves the estimates incomplete.

As an example, consider the zone diagram of a hypothetical city of 200,000 as shown in Figure II-31. Nine residential zones are assumed, lettered A through J. The CBD is indicated, along with two major shopping centers and four major work areas. Mileages from the residential areas to the other zones are as given in Table II-17.

Table II-17
DISTANCES FROM RESIDENTIAL ZONES TO OTHER ZONES

From Zone	Miles to:						
	CBD	Zone M	Zone N	Zone W	Zone X	Zone Y	Zone Z
A	2	2	7	3	2	3	6
B	3	4	6	6	2	3	7
C	3	6	3	6	3	1	6
D	5	9	1	7	6	5	4
E	2	6	3	4	3	2	3
F	3	7	3	4	5	4	1
G	2	5	5	2	4	4	2
H	1	3	6	2	2	3	4
J	4	2	8	2	4	5	6



METROPOLITAN AREA

NOSUCH CITY

ZONE	EMPLOYEES	FLOOR SPACE
C.B.D.	20,000	2,000,000
M	1,500	500,000
N	500	200,000
W	1,000	—
X	8,000	—
Y	10,000	—
Z	3,000	—
	<hr/> 44,000	

FIGURE II-31.

Assumed basic data for the residential zones are given in Table II-18. Population was calculated at 3.2 to 3.3 persons per dwelling unit, and vehicle ownership ratios were assumed to vary from 0.40 to 0.87.

Table II-18
DWELLING UNIT DATA

<i>Zone</i>	<i>Population</i>	<i>No. of Dwelling Units</i>	<i>No. of Vehicles</i>	<i>Vehicles per Dwelling Unit</i>
A	27,000	8,300	7,000	0.84
B	24,000	7,500	6,000	0.80
C	23,000	7,200	5,000	0.69
D	21,000	6,500	4,000	0.62
E	23,000	7,000	3,500	0.50
F	16,000	5,000	4,000	0.80
G	29,000	9,000	6,400	0.71
H	13,000	4,000	1,600	0.40
J	24,000	7,500	6,500	0.87
	200,000	62,000	44,000	0.71

Trips from Residential Zones

Using the curves of Figures II-9 and II-10, estimates were made of the number of trips for various purposes originating in the nine residential areas. Shown in Table II-19, the vehicles per dwelling unit ratio is first used to determine a rate of trip generation per 1,000 dwelling units. For example, the vehicle ownership rate for Zone A is given as 0.84. To estimate work trips, the work-trip generation is found from Figure II-9 or II-10 to be 1,000 trips per 1,000 dwelling units, so that the total daily work trips originating in Zone A would be 8,300.

The total number of work trips estimated from all zones in the above manner is 62,400. A study of Bureau of Census data shows that in 1950, employed persons amounted to 37 percent of the population of the country. The rate varied from 35 percent to 39 percent in four major regions. Applying the average value of

Table II-19

DISTRIBUTION OF TRIPS FROM RESIDENTIAL ZONES, BY PURPOSE OF TRIP

From Zone	No. of Dwelling Units	Veh. per D.U.	Work Trips			Shopping Trips						Total Trips
			Total	To Major Work Centers (70%)	To Unknown Dest.	Total	Shopping Goods	Con- venience Goods	Busi- ness Trips	Soc.- Rec. Trips	Other Trips	
68 A	8,300	0.84	8,300	5,800	2,500	3,900	1,660	2,240	2,240	6,810	3,900	25,150
B	7,500	0.80	7,500	5,300	2,200	3,300	1,500	1,800	1,880	5,930	3,230	21,840
C	7,200	0.69	7,200	5,000	2,200	2,660	1,440	1,220	1,440	4,830	2,520	18,650
D	6,500	0.62	6,500	4,600	1,900	2,210	1,300	910	1,240	3,770	1,950	15,670
E	7,000	0.50	7,200	5,000	2,200	2,030	1,400	630	840	3,220	1,540	14,830
F	5,000	0.80	5,000	3,500	1,500	2,200	1,000	1,200	1,250	3,950	2,150	14,550
G	9,000	0.71	9,000	6,300	2,700	3,510	1,800	1,710	1,800	6,210	3,240	23,760
H	4,000	0.40	4,200	2,900	1,300	920	800	120	280	1,480	720	7,600
J	7,500	0.87	7,500	5,300	2,200	3,600	1,500	2,100	2,100	6,450	3,750	23,400
ALL	62,000	0.71	62,400	43,700	18,700	24,330	12,400	11,930	13,070	42,650	23,000	165,450

37 percent to the assumed city population of 200,000, we obtain a theoretical 74,000 workers.

However, it is logical that not all workers would make a work trip every day. Included in the 74,000 would be those who work at their place of residence, those walking to work, absentees due to illness, vacation, days off, and so on. The estimated total of 62,400 trips amounts to about 85 percent of the 74,000 obtained as above, which does not seem unreasonable.

Another important factor was considered in completing the "work trip" section of Table II-19. It would be almost impossible to estimate the destinations of all the work trips from any residential zone. Part of the trips would be made to small neighborhood stores, service establishments, and other places of business scattered throughout the city and outside the metropolitan area. A study in San Francisco⁴⁵ showed that 70 percent of the trips to work made into and within the city had destinations in the major working areas, while 30 percent were made to locations scattered throughout the residential areas.

Applying the 70 percent factor to the total work trips gives the values shown in Table II-19 for trips to the major work centers.

Shopping trip totals were estimated from Figures II-9 and II-10 by first obtaining a trip rate based on the vehicle ownership factor, and applying this to the number of dwelling units. Total trips were broken down into shopping-goods trips and convenience-goods trips by use of the values suggested by Voorhees, Sharpe, and Stegmaier. Adopting their finding of one shopping-goods trip per family per five-day week, these trips are estimated for each zone by simply dividing the number of dwelling units by five, so as to obtain the average number of daily trips. Subtracting these trips from total shopping trips leaves the number of trips made for convenience goods.

The estimated number of trips for business, social-recreational, and other purposes was obtained as explained above, by applying the trip rate factors from Figure II-9 or II-10 to the number of dwelling units in each zone.

⁴⁵ *Daily Trips in San Francisco*, Department of City Planning, City and County of San Francisco, June, 1955.

Distribution of Shopping Trips

Shopping-goods trips, which total about 50 percent of all shopping trips from the nine residential zones (Table II-19), can be distributed according to Casey's statement of Reilly's Law.

It is assumed that trips for shopping goods will be divided between the CBD, Zone M, and Zone N in direct proportion to the floor space of each of these shopping centers, and in indirect ratio to the square of the distance from each of these centers to the residential zone in question.

The calculations for Zone A are as follows:

$$T_{cbd} = \left[\frac{\frac{F_{cbd}}{(D_{cbd})^2}}{\left(\frac{F_{cbd}}{(D_{cbd})^2} + \frac{F_m}{(D_m)^2} + \frac{F_n}{(D_n)^2} \right)} \right] T_s$$

where T_{cbd} = shopping goods trips from Zone A to the CBD.

F_{cbd}, F_m, F_n = floor areas of shopping centers or 2,000,000, 500,000 and 200,000 respectively.

D_{cbd}, D_m, D_n = distance in miles from Zone A to the shopping centers, or 2, 2, and 7 miles, respectively.

T_s = total shopping-goods trips originating in Zone A, or 1660 trips.

Substituting,

$$\begin{aligned} T_{cbd} &= \frac{\frac{2,000,000}{2^2}}{\frac{2,000,000}{2^2} + \frac{500,000}{2^2} + \frac{200,000}{7^2}} \times 1660 \\ &= \frac{500,000}{629,080} \times 1660 \\ &= 1320 \text{ trips} \end{aligned}$$

Similarly,

$$\begin{aligned} T_m &= \frac{125,000}{629,080} \times 1660 \\ &= 330 \text{ trips} \end{aligned}$$

and

$$\begin{aligned} T_n &= \frac{4,080}{629,080} \times 1660 \\ &= 10 \text{ trips} \end{aligned}$$

Similar calculations for the other residential zones result in the trip distribution shown in Table II-20. In actual practice, it would be preferable to substitute a travel-time value for the distances used in this example.

The convenience-goods trips from each residential zone would be distributed in a somewhat similar manner, based on a study of

Table II-20
DISTRIBUTION OF SHOPPING-GOODS TRIPS FROM RESIDENTIAL ZONES

From Zone	Total Shopping Trips	Convenience Goods Trips	Shopping Goods Trips			
			Total	To CBD	To Zone M	To Zone N
A	3,900	2,240	1,660	1,320	330	10
B	3,300	1,800	1,500	1,290	180	30
C	2,660	1,220	1,440	1,240	80	120
D	2,210	910	1,300	360	30	910
E	2,030	630	1,400	1,310	30	60
F	2,200	1,200	1,000	870	40	90
G	3,510	1,710	1,800	1,700	70	30
H	920	120	800	780	20	—
J	3,600	2,100	1,500	740	740	20
ALL	24,330	11,930	12,400	9,610	1,520	1,270

retail outlets in each zone. The major shopping centers would, of course, attract a large proportion of such trips from the homes in their immediate areas. Except where unusual circumstances dictate otherwise, convenience-goods trips should be distributed within an area defined by a five to ten-minute travel radius.

Distribution of Work Trips

The work trips previously estimated from each of the residential zones to the major work areas can be distributed by methods suggested by Voorhees and Carroll. As Voorhees distributes work trips from the work areas back to the residential areas, it has been necessary to assume a total number of work trips in the seven major work zones equal to the previously calculated number of

Table II-21

DISTRIBUTION OF TRIPS TO MAJOR WORK CENTERS FROM RESIDENTIAL AREAS

	<i>From Zone</i>	<i>To CBD</i>	<i>To Industrial Zones</i>				<i>To Shopping Centers</i>		<i>Total</i>	
			<i>W</i>	<i>X</i>	<i>Y</i>	<i>Z</i>	<i>M</i>	<i>N</i>	<i>Calculated</i>	<i>Assumed¹</i>
98	A	2,700	153	1,370	1,500	283	323	38	6,367	5,800
	B	2,400	73	1,260	1,380	212	198	49	5,572	5,300
	C	2,300	68	980	980	244	121	86	4,779	5,000
	D	2,100	54	470	810	347	50	61	3,892	4,600
	E	2,300	105	980	1,610	463	121	86	5,665	5,000
	F	1,600	74	450	720	249	68	60	3,221	3,500
	G	2,900	205	970	1,310	724	191	66	6,366	6,300
	H	1,300	95	690	760	219	133	26	3,223	2,900
	J	2,400	173	830	930	259	295	28	4,915	5,300
	ALL	20,000	1,000	8,000	10,000	3,000	1,500	500	44,000	43,700

¹ Original work-trip totals from residential zones as previously estimated. See Table II-19.

such trips originating in the residential areas, or about 44,000 trips. Total work trips or “employees” in each of the work zones are as shown in Figure II-31 and as the column totals in Table II-21.

The work trips to the CBD were distributed according to Carroll’s findings that CBD workers are almost uniformly distributed throughout the city population. On this basis, CBD work trips from each residential zone are found by the formula

$$\text{Trips} = \frac{(\text{zone population})}{(\text{city population})} \times (\text{Total CBD Work Trips})$$

For Zone A, the calculation is

$$\begin{aligned} \text{Trips} &= \frac{27,000}{200,000} \times 20,000 \\ &= 2700 \end{aligned}$$

Similar calculations for all nine zones result in the values shown in the second column of Table II-21.

The estimates for the work trips to the other six work zones were made according to Voorhees’ method, in which the first step is to calculate the average work-trip ratio for each work zone by use of the formula.

$$\text{Average Work-Trip Ratio} = \frac{(\text{Total Work Trips to Zone})}{(\text{Total Work Trips in City})}$$

For Zone Y, as an example, the average work-trip ratio is calculated as

$$\text{Average W.T.R.} = \frac{10,000}{44,000} = 0.2273$$

The maximum work-trip ratio is then assumed as 150 percent of this value, or about 0.341.

The average and maximum work-trip ratios for all work zones outside the CBD for the hypothetical city are as shown in Table II-22.

Continuing the calculations for Zone Y, the approximate value of the maximum work-trip ratio is entered on the vertical scale of the assumed curve shown in Figure II-32, and work-trip ratios are then estimated for each of the residential zones according to

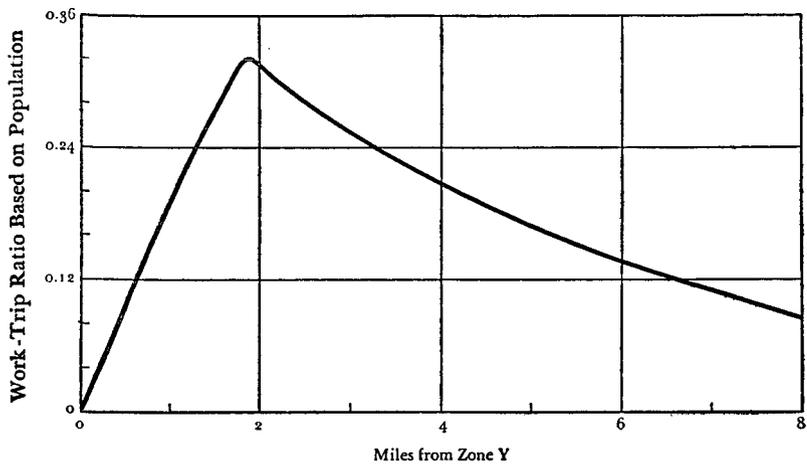


FIGURE II-32. Theoretical curve developed for Zone Y.

SOURCE: A. M. Voorhees.

their respective distances from the work zone. The estimates for Zone Y are shown in Table II-23.

Table II-22
AVERAGE AND MAXIMUM WORK-TRIP RATIOS FOR WORK ZONES

<i>Work Zone</i>	<i>Average Work-Trip Ratio</i>	<i>Maximum¹ Work-Trip Ratio</i>
W	0.0227	0.034
X	0.1818	0.273
Y	0.2273	0.341
Z	0.0682	0.102
M	0.0341	0.051
N	0.0114	0.017

¹ Assumed to be about 150% of average work-trip ratio.

The first estimate of the number of work trips from each of the residential zones is obtained by multiplying the work-trip ratio by the total number of work trips (to major work centers) originating in each zone, as shown in the column headed "trips to Zone Y." An adjustment factor is calculated to bring the total of these trips (9,650) in agreement with the known total (10,000),

Table II-23
ESTIMATED DISTRIBUTION OF WORK TRIPS DESTINED FOR ZONE Y

<i>From Zone</i>	<i>Miles to Zone Y</i>	<i>Work-Trip Ratio</i>	<i>Total Work Trips</i>	<i>Trips to Zone Y (3) × (4)</i>	<i>Adjusted Trips to Zone Y</i>
(1)	(2)	(3)	(4)	(5)	(6)
A	3	0.25	5,800	1,450	1,500
B	3	0.25	5,300	1,330	1,380
C	1	0.19	5,000	950	980
D	5	0.17	4,600	780	810
E	2	0.31	5,000	1,550	1,610
F	4	0.20	3,500	700	720
G	4	0.20	6,300	1,260	1,310
H	3	0.25	2,900	730	760
J	5	0.17	5,300	900	930
				9,650	10,000

Adjustment factor = 10,000 ÷ 9,650 = 1.038.

and this factor is then applied to each of the zone totals. The adjusted number of trips from each residential zone is shown in the last column of the table.

A similar procedure was used to estimate the work trips to all other work zones, as shown in Table II-21.

The last two columns of Table II-21 show that some discrepancies result when comparing the total calculated work trips for each zone, according to Voorhees' method, with the number of work trips originally assumed on the basis of population and motor vehicle registration.

An alternate method of distributing work trips from the residential areas makes use of Voorhees' latest theory. According to this theory, work areas attract workers directly as the size of the work area (number of employees), and indirectly as the square root of the distance between residential area and work area.

Casey's formula for shopping trips can be re-written to express work trip attraction as follows:

$$W_{1,a} = \left[\frac{\frac{E_a}{\sqrt{D_{1,a}}}}{\frac{E_a}{\sqrt{D_{1,a}}} + \frac{E_b}{\sqrt{D_{1,b}}} + \frac{E_c}{\sqrt{D_{1,c}}} + \frac{E_d}{\sqrt{D_{1,d}}} + \dots + \frac{E_z}{\sqrt{D_{1,z}}}} \right] W_1$$

where

- W_1 = number of workers in residential area 1;
- $W_{1,a}$ = number of workers from residential area 1 going to work area A;
- $E_a, E_b, E_c,$ etc. = number of employees in employment areas A, B, C, etc.;
- $D_{1,a}, D_{1,b}, D_{1,c}$ etc. = the distance (preferably the driving time) between neighborhood 1 and the respective employment centers.

Using this formula to distribute work trips from residential area A to work area M, the formula would be written:

$$W_{a,m} = \left[\frac{\frac{E_m}{\sqrt{D_{a,m}}}}{\frac{E_m}{\sqrt{D_{a,m}}} + \frac{E_n}{\sqrt{D_{a,n}}} + \frac{E_w}{\sqrt{D_{a,w}}} + \frac{E_x}{\sqrt{D_{a,x}}} + \frac{E_y}{\sqrt{D_{a,y}}} + \frac{E_z}{\sqrt{D_{a,z}}}} \right] W_a$$

Assuming that work trips to the CBD are as previously calculated, (Table II-21), distances are as shown in Table II-17, and work area employees are as shown in Figure II-31, values are substituted as follows:

$$\begin{aligned} W_{a,m} &= \left[\frac{\frac{1500}{\sqrt{2}}}{\frac{1500}{\sqrt{2}} + \frac{500}{\sqrt{7}} + \frac{1000}{\sqrt{3}} + \frac{8000}{\sqrt{2}} + \frac{10000}{\sqrt{3}} + \frac{3000}{\sqrt{6}}} \right] (5800-2700) \\ &= \left[\frac{1060}{1060 + 189 + 577 + 5660 + 5770 + 1230} \right] 3100 \\ &= \frac{1060}{14486} \times 3100 \\ &= 227 \end{aligned}$$

Similarly, $W_{a,n} = \frac{189}{14486} \times 3100 = 40$

$$W_{a,w} = \frac{577}{14486} \times 3100 = 124$$

$$W_{a,x} = \frac{5660}{14486} \times 3100 = 1210$$

$$W_{a,y} = \frac{5770}{14486} \times 3100 = 1236$$

$$W_{a,z} = \frac{1230}{14486} \times 3100 = 263$$

Similar calculations are used to distribute work trips from the other residential zones to all work areas (other than the CBD) as shown in Table II-21a. A comparison of the column totals with the assumed employment in each of the zones (shown in parenthesis) indicates fairly close agreement.

Table II-21a
DISTRIBUTION OF TRIPS TO MAJOR WORK CENTERS
FROM RESIDENTIAL AREAS (ALTERNATE METHOD)

From Zone	To CBD	To Industrial Zones				To Shopping Centers		Total
		W	X	Y	Z	M	N	
A	2,700	124	1,210	1,236	263	227	40	5,800
B	2,400	85	1,180	1,200	235	155	45	5,300
C	2,300	65	730	1,570	193	97	45	5,000
D	2,100	89	770	1,050	355	118	118	4,600
E	2,300	90	840	1,290	315	112	53	5,000
F	1,600	73	525	735	441	83	43	3,500
G	2,900	187	1,070	1,340	565	178	60	6,300
H	1,300	77	616	628	163	94	22	2,900
J	2,400	176	1,000	1,110	305	265	44	5,300
	20,000	966	7,941	10,159	2,835	1,329	470	43,700
		(1,000)	(8,000)	(10,000)	(3,000)	(1,500)	(500)	

Total Trips to Central Business District

The work done by F. H. Wynn and G. B. Sharpe enable us to make rough estimates of the total travel to the central business district, for all purposes, as related to the distance of the zone of origin from the destination.

More work is needed to clarify the effect of modifying factors, particularly city size. The evidence is strong that the rate of such travel varies inversely with city size, as brought out by Foley. The overall rate of CBD travel in this example amounts to about 245 CBD trips per thousand population, which is in line with Foley's findings for a city of 200,000 population.

Sharpe reported, with regard to trips made in Washington, D. C., that CBD trips per thousand population dropped from about 250 within a four-mile radius to 150 or less beyond six

miles from the CBD. Wynn's study of nine cities indicated that the rate of inbound trips dropped from about 250 to 300 per thousand population at 2.5 miles to values of about 150 to 200 per thousand at 5.5 miles from the CBD. Both studies indicated a drop in trip volumes from CBD "fringe" areas, probably because of unreported walking trips.

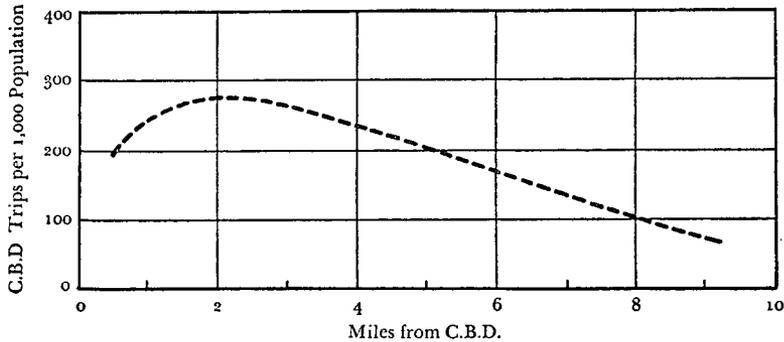


FIGURE II-33.

An assumed curve based on these two studies is shown in Figure II-33. Relating this curve to the residential zones in our hypothetical city results in the values shown in Table II-24. Also

Table II-24

TOTAL TRIPS TO CBD FOR ALL PURPOSES FROM RESIDENTIAL ZONES

<i>From Zone</i>	<i>Miles from CBD</i>	<i>Zone Population</i>	<i>Trips per 1,000 Population</i>	<i>Estimated Total Trips to CBD</i>	<i>Work Trips</i>	<i>Shopping Trips</i>	<i>All Other Trips</i>
A	2	27,000	270	7,290	2,700	1,320	3,270
B	3	24,000	250	6,000	2,400	1,290	2,310
C	3	23,000	250	5,750	2,300	1,240	2,210
D	5	21,000	180	3,780	2,100	360	1,320
E	2	23,000	270	6,210	2,300	1,310	2,600
F	3	16,000	250	4,000	1,600	870	1,530
G	2	29,000	270	7,830	2,900	1,700	3,230
H	1	13,000	230	2,990	1,300	780	910
J	4	24,000	220	5,280	2,400	740	2,140
ALL		200,000		49,130	20,000	9,610	19,520

shown in this table are the previously estimated volumes of work trips and shopping trips to the CBD from each of the residential areas, and the resulting volumes of trips for "all other" purposes. These trips amount to about 40 percent of the total inbound volumes.

Evaluation of Methods

The estimates described thus far are for *one-way* travel originating in the residential areas, the total of which should constitute approximately forty percent of all daily trips made in the city. Another forty percent would be made up of the return trips to the residential areas. The remaining twenty percent of the daily travel would consist of trips between the major trip-generating centers, with neither origins nor destinations in the residential areas. A sizeable part of such trips would be made by commercial vehicles.

Of the 165,450 trips estimated to originate in the residential areas (Table II-19) a total of 68,030 or forty-one percent has been accounted for with regard to both purpose and destination. These are the work trips to major employment centers and the shopping trips.

Another 19,520 trips to the CBD (Table II-24) have been given direction, but purpose of the trips is a matter of conjecture. Many undoubtedly could be labeled as business, social-recreational, or other, as trips of these types from the residential areas have not been distributed. Not having any real basis on which to proceed, however, the authors prefer to await further research.

A total of 87,550 trips, or about fifty-three percent of all those trips originating in the residential areas, is therefore at least partly accounted for with regard to direction and purpose. If we can assume that these trips are duplicated in the reverse direction (return home), then we have in effect made an estimate of fifty-three percent of the eighty percent of all daily trips that supposedly have the home as the origin or destination, or about forty-two percent of all the daily movements of the urban area.

While the ability to estimate less than half of the daily traffic

movements is far from satisfactory, a reasonably accurate method of doing so could be very useful. Critical traffic hours are associated with the daily *to work* and *from work* trips, and a good start has been made in synthesizing the patterns and volumes of such movements.

Trips generated by the CBD are unquestionably the major traffic problem in all cities. A proved method of estimating their magnitude on the basis of location and general characteristics of the zone of origin would facilitate planning the radial street system.

Need for Further Research

The largest single group of trips remaining to be distributed from the residential areas is the social-recreational group. Further research is needed to develop distribution patterns for trips of this type. A part of the information needed is a division of the travel into two main classifications, *social* and *recreational*. Social trips are generally considered as those made to the homes of friends or acquaintances. Recreational trips are made to places offering entertainment, sporting events, or other activities of a cultural or recreational nature.

Obviously, the one type would be made primarily between two residential areas. The other would be made most often from the residential area to one of several areas in the city where the desired type of recreation might be offered. There is little information available on the patterns developed by such trips. It would seem reasonable to suppose there would be marked differences in the generating power and trip-distribution patterns of such diverse establishments as downtown theaters vs. neighborhood theaters, the ballet and the concert hall vs. the drive-in movies, and the major league baseball park vs. the high-school stadium.

Also to be investigated is the social inter-action between the various residential sections of the city, where such factors as income, race and religion, customs, and other characteristics may be of greater importance than availability of transportation or

spacial separation in determining the amount of travel from one zone to another.

The trips classified as *business* might well be distributed to the CBD and outlying business centers according to *shopping-goods trip* formula. The authors have not located any studies to justify doing so. Extreme variations in the numbers of such trips between individual origin and destination studies indicate the need for more specific and uniform identification of these trips in urban traffic studies.

The catch-all classification of *other trips* as used in this chapter refers to the total of all trips normally labeled *school, eat meal, medical-dental, change mode, and serve passenger* in the standard origin-destination survey. They constitute a small percentage of the total daily trips, and except for *school* and *change mode* trips the majority of them would be destinations in the major business areas of the city. Distribution could probably be made, with little error, in accordance with the *shopping-goods trip* formula.

A basis for estimating the pattern of the twenty percent of daily trips that neither begin nor end in the residential areas is almost completely lacking. As previously indicated, many of these trips are probably accounted for in the movements of commercial vehicles. Separate studies of truck movements might therefore serve to establish these patterns. Multiple-purpose trips originating in the residential areas would also be important in this respect.

Additional research is needed to provide a basis for estimating these unknown travel patterns, and to confirm or modify the estimates already made. Origin and destination study data collected by the several state highway departments may contain the key to these unknowns.

Considering the potential value of a complete and reasonably accurate method of estimating present and future travel patterns from basic land use and population data, the importance of a co-operative effort towards developing such a technique can hardly be overemphasized.

SELECTED REFERENCES FOR SUPPLEMENTAL READING

1. *Daily Trips in San Francisco*. Department of City Planning, City and County of San Francisco. June 1955.
2. Carroll, J. Douglas, Jr. *The Relation of Homes to Work Places and the Spacial Pattern of Cities*. Social Forces, Vol. 30, No. 3, 1952. Reprint.
3. Foley, Donald L. *The Daily Movement of Population into Central Business Districts*. American Sociological Review, Vol. 17, No. 5, October 1952.
4. Aström, Torsten R. *Laws of Traffic and Their Applications to Traffic Forecasts with Special Reference to the Sound Bridge Project*. Royal Institute of Technology, Stockholm. 1953.
5. Adams, Leonard P. and Mackesey, Thomas W. *Commuting Patterns of Industrial Workers*. Housing Research Center, Cornell University, Ithaca. 1955.
6. Bulletin 19, *Parking*. Highway Research Board, Washington, D.C. 1949.
7. Bulletin 67, *Some Economic Effects of Highway Improvement*. Highway Research Board, Washington, D.C. 1953.
8. Bulletin 79, *Travel to Commercial Centers*. Highway Research Board, Washington, D.C. 1953.
9. Special Report 11, *Parking as a Factor in Business*. Highway Research Board, Washington, D.C. 1953.
10. Special Report 11-A, *Shopper Attitudes*. Highway Research Board, Washington, D.C. 1955.
11. Special Report 11-B, *Shopping Habits and Travel Patterns*. Highway Research Board, Washington, D.C. 1955.
12. Wynn, F. Houston. *Intra-City Traffic Movements*. Bulletin 119, Highway Research Board, Washington, D.C. 1955.
13. Mylroie, Willa. *Evaluation of Inter-City Travel Desire*. Bulletin 119, Highway Research Board, Washington, D.C. 1955.
14. *Interregional Highways*. House Document No. 379. U.S. Government Printing Office, Washington, D.C. 1944.
15. O'Flaherty, Daniel. *Arlington Shopping and Travel Study*. Highway Transport Research Branch, Bureau of Public Roads. 1952. Mimeo.
16. *Motor-Vehicle-Use Studies in Six States*. Public Roads, Vol. 28, No. 5. December 1954. U.S. Government Printing Office, Washington, D.C.
17. *A Motor Vehicle Use Survey of Missouri*. Division of Highway Planning, Missouri State Highway Department and Bureau of Public Roads. 1952.
18. *A Method of Rural Road Classification*. Michigan State Highway Department. January 1950.
19. Fratar, Thomas J. *Vehicular Trip Distribution by Successive Approximations*. Traffic Quarterly, January 1954. Eno Foundation, Saugatuck, Connecticut.
20. Smith, Larry. *Maintaining the Health of Our Central Business Districts*. Traffic Quarterly, April 1954. Eno Foundation.

21. Iklé, Fred Charles. *Sociological Relationship of Traffic to Population and Distance*. Traffic Quarterly, April 1954. Eno Foundation.
22. McMillan, Samuel C. *Decentralization of Retail Trade*. Traffic Quarterly, April 1954. Eno Foundation.
23. Row, Arthur T., *An Approach to O-D Data Analysis*, Traffic Quarterly, January 1955. Eno Foundation.
24. Carroll, J. Douglas, Jr. *Defining Urban Trade Areas*, Traffic Quarterly, April 1955. Eno Foundation.
25. Casey, Harry J., Jr. *The Law of Retail Gravitation Applied to Traffic Engineering*. Traffic Quarterly. July 1955. Eno Foundation.
26. Kelley, Eugene J. *Retail Structure of Urban Economy*, Traffic Quarterly, July 1955. Eno Foundation.
27. Reilly, William J. *The Law of Retail Gravitation*, 2nd Edition. Pilsbury Publishers, Inc., New York. 1953.
28. Hamburg, John R. *Land Use and Traffic Generation in the Detroit Metropolitan Area*. Detroit Metropolitan Area Traffic Study, Detroit, Michigan. 1955. Mimeo.
29. Bevis, Howard W. *An Analysis of the Factors Affecting Zonal Interchange Volumes*. Detroit Metropolitan Area Traffic Study, Detroit, Michigan. 1955. Mimeo.
30. Bevis, Howard W. *A Method of Forecasting Zonal Interchange Volumes*. Detroit Metropolitan Area Traffic Study, Detroit, Michigan. 1955. Mimeo.

CHAPTER THREE

GENERATION OF TERMINALS

There are two distinctive types of terminal facilities—the facility for parking and storage, and the facility serving as a medium in mode translation, e. g. an airport where, with the termination of a trip by plane, another trip by motor vehicle is begun.

I. Parking and Storage

Parking patterns are dynamic and vary with hour of day, day of week, and month of year. Patterns are affected by the level of economy, business activity, size and type of city; capacity and location of parking facilities; convenience and cost of parking; adequacy of urban arterials and adequacy of mass transit; proximity, type and size of other cities; existence of suburban shopping centers, and trip purpose. There may be others.

This chapter does not provide a guide to determine parking needs. It reviews studies that equate the performance of present facilities to other readily available data, such as retail sales volumes. The objective is to measure actual rather than potential usage. It is generally believed that the potential is much greater than the actual usage, and that it is not economically feasible to provide space for every last vehicle in the total potential.

Inasmuch as parking facilities generally provide less accommodation than the potential, it is safe to assume that existing downtown parking facilities are receiving maximum usage. This is a necessary assumption if the findings derived under such conditions are to be useful for estimating.

Central Business District Parking Volume

Research conducted to determine the influence of population, sales, and employment on parking reported¹ by S. T. Hitchcock

¹ Influence of Population, Sales and Employment on Parking. S. T. Hitchcock, Proceedings, Highway Research Board, Vol. 32, pp. 464-485.

of the Bureau of Public Roads gives several methods for determining the approximate total volume of parkers in a city between 10:00 a.m. and 6:00 p.m. One provides "within limits of reasonable accuracy" the relation between urban population and the number of parkers per million of G.A.F. sales² as shown in Fig. III-1. The family of curves in this figure shows the relation for cities having dominant characteristics as follows:

1. Retail (Retail Trade-Manufacturing Employment Ratio ranging from 1:0.1 to 1:1.0)
2. Average (Retail Trade-Manufacturing Employment Ratio ranging from 1:1.0 to 1:2.0)
3. Industrial (Retail Trade-Manufacturing Employment Ratio ranging from 1:2.0 to 1:6.0)

A separate statistical evaluation by Hitchcock provided the following formula to produce an estimate of average parking accumulation for cities with less than 50,000 population:

$$X = 2547 + 0.0125 X_2 + 0.0894 X_3 + 0.0362 X_4$$

where:

- X = 1000 times the log of the average parking accumulation.³
(X is a logarithmic number and is converted into the estimated number of parkers by use of logarithmic tables.)
- X₂ = inbound cordon count of vehicles, 10:00 a.m. to 6:00 p.m.
- X₃ = number of parking spaces in the central business district.
- X₄ = number of employees in retail and service trades.

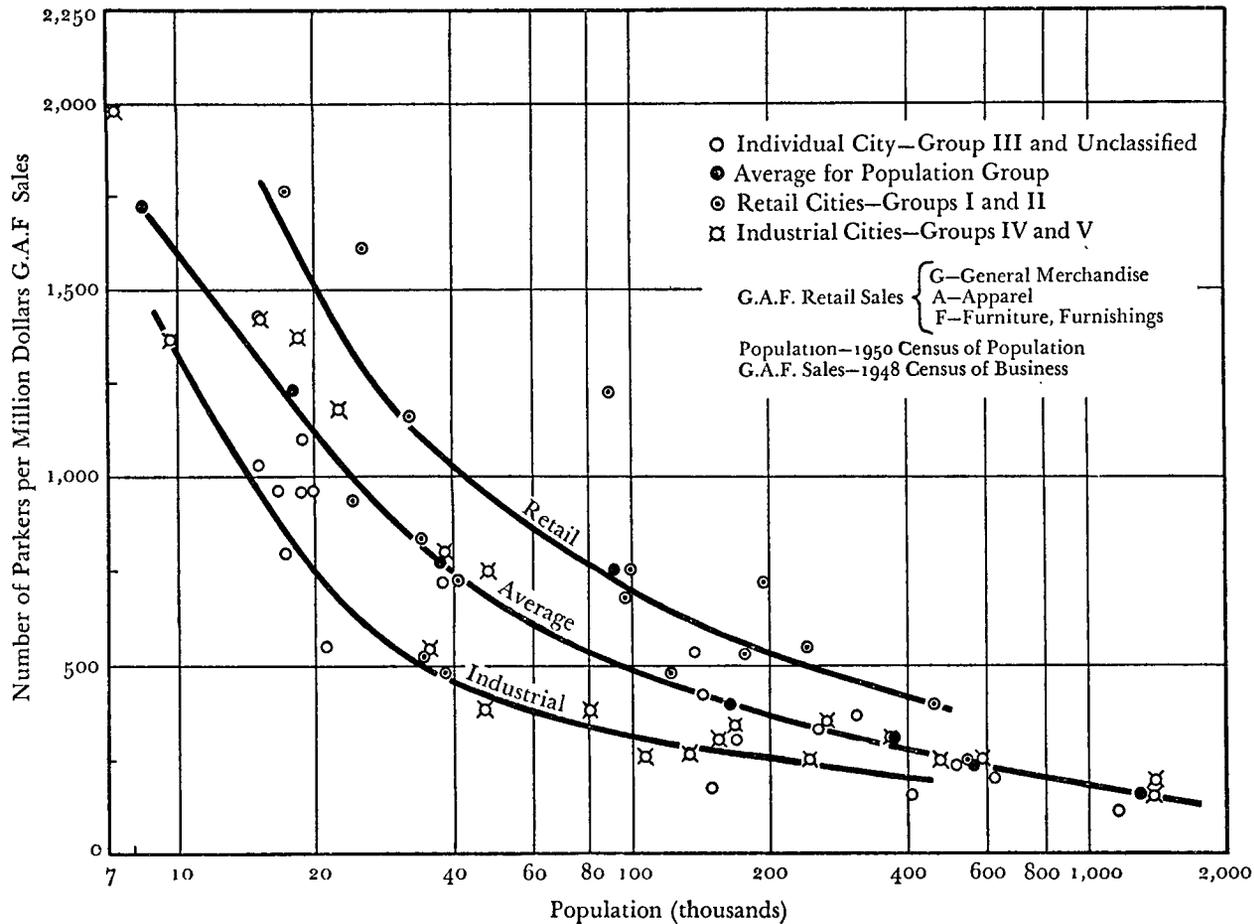
In another phase of the research by Hitchcock, multiplying factors were derived to convert the average parking accumulation to daily number of parkers and peak hour parking:

<i>Population Group</i>	<i>Factor for Daily Parkers</i>	<i>Factor for Peak Hour Parking</i>
Under 25,000	8.3	1.27
25,000 to 50,000	7.1	1.00
50,000 to 100,000	6.3	0.90
100,000 to 250,000	5.5	0.80
250,000 to 500,000	4.5	0.66
500,000 to 1,000,000	4.2	0.60
1,000,000 and over	3.3	0.46

If desired, the above values may be graphed for purposes of interpolation.

² G-General merchandise, A-Apparel, F-furniture, appliances, and furnishings.

³ Average parking accumulation: The number of vehicles parked at a particular time is the accumulation at that time. The average parking accumulation is the average of the volumes parked at each ½ hour interval from 10:00 a.m. to 6:00 p.m.



SOURCE: S. T. Hitchcock.

FIGURE III-1. Relation between urban population and the number of parkers per million dollars of G.A.F. retail sales.

In planning the individual facility the peak hour demand should be satisfied if possible. This may be impossible in the larger city. Peak accumulation occurs at about 2 p.m. but peak parking activity occurs between 7 a.m. and 9 a.m.

It has been estimated that a parking index of fifteen (15 car spaces per thousand gross square feet of rentable area) is necessary to completely handle the December seasonal peak in large suburban shopping centers, and an index of seven is a minimum requirement in a city with a population of 200,000 or over. It is unusual to find a parking index in excess of 0.75 or 0.50.⁴ Dayton Ohio, however with a metropolitan population close to 500,000 has an index of 1.17.

Sears, Roebuck and Company has used annual retail sales of \$10,000 per car space as a criterion for planning their parking space needs. Supermarkets have used \$15,000 per car space.⁵ One car space for \$3,000 (for 1940 dollar) in G.A.F. sales has been used where mode of travel was limited to the automobile.⁶

Central Business District Supply and Demand

In addition to the estimates derived by correlating parking with economic activity and city size, studies have been made to determine for cities of various population groups the parking space supply and demand.

In estimating CBD parking volumes or in making a forecast of trends, it is desirable to use several methods, including projection, correlation and analogy in order to test the results. The following tables provide basic information to assist in estimating by analogy.

Parking potential is unknown. Parking demand is measured under present conditions and volumes noted as "demand" are related to the destinations of actual trips, i.e. the volume of trips desiring parking space at certain specific blocks. *Excess demand* means the desire to park at a specific location exceeds the capacity

⁴ "Factors in Planning Regional Shopping Centers," Kenneth C. Welch, Bulletin 79, Highway Research Board, 1953.

⁵ See 1. on page 2.

⁶ Bulletin 19. p. 71, Highway Research Board.

Table III-1

PARKING SPACE SUPPLY AND USAGE IN CENTRAL BUSINESS DISTRICTS

	SUPPLY				USAGE					
	Population Group (Thousands)	No. of Cities	Spaces per 1,000 Pop.			No. of Cities	Parkers per 1,000 Pop.		% Comm.	Parking Ratio, Peak Hr. to Avg. Hr.
			Curb	Off-Street	Total		Total 10 A.M.— 6 P.M.	Max. Accum.		
601	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Under 25	5	54	36	90	5	432	62	14	1.22
	25-50	3	41	25	66	3	239	43	13	1.13
	50-100	2	23	34	57	2	164	30	11	1.15
	100-250	8	17	25	42	7	112	28	13	1.15
	250-500	6	7	21	28	5	83	21	13	1.15
	500 and over	2	3	9	12	2	34	11	13	1.11

SOURCE: "Some Travel and Parking Habits Observed in Parking Studies," R. H. Burrage and S. T. Hitchcock, Bulletin 19, Highway Research Board, 1949.

Table III-2
PARKING SPACE SUPPLY AND DEMAND
 The Use of Space in the Entire Central Business District, and the Relation of Demand and Supply
 in the Core Area, in Cities of Six Population Groups

	<i>Central Business District</i>			<i>Core¹</i>				
	<i>Population Group (thousands)</i>	<i>Number of Cities</i>	<i>Present Usage Space Hours</i>		<i>Number of Cities</i>	<i>Space Hours</i>		<i>Ratio Demand to Supply</i>
			<i>Number</i>	<i>Per 1,000 Population</i>		<i>Demand</i>	<i>Supply</i>	
	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	
110	Less than 25	4	8,654	511	4	2,950	2,250	1.31
	25-50	3	9,799	303	2	3,766	2,868	1.31
	50-100	2	14,632	220	2	4,290	2,964	1.45
	100-250	5	33,659	255	5	16,290	10,663	1.67
	250-500	4	51,578	184	3	20,828	6,505	3.27
	500 and over	2	65,846	99	2	28,590	6,649	4.67
		20			18			

¹ The core is that portion of the Central Business District where land values are generally highest, where in each block of several contiguous blocks, the demand for parking space in each exceeds the supply.

SOURCE: (Same as Table III-1).

at that particular location, and the excess must seek space elsewhere. The amount of demand is determined from destinations of drivers who parked in the CBD.

A comparison of columns five and eight in Table III-1 discloses that (1) CBD spaces per capita of population decrease with increase in city size, and (2) the maximum accumulation approaches the supply as size of city increases. This may be interpreted to mean that the excess of potential over actual usage becomes greater as city size increases. The potential CBD parking does not increase in direct population to city size inasmuch as the friction of time and space is reflected in the potential. Table III-2 provides basic data in space hour supply and demand.

Table III-2 indicates that sufficient supply is not available in any of the population groups exactly where the supply is desired, and that as the size of the city grows there is less chance of finding a parking space in the immediate location desired at the core. Whether it is economically feasible to balance supply with demand requires case studies. This table does lead to the conclusion that existing supply of parking space in the core should have capacity usage if rates are reasonable.

Duration of parking by trip purpose will provide a method of spreading the volume of parking activity by type of generator. The following table provides these data:

Table III-3
PARKING DURATIONS IN CBD
Average Length of Time Parked for Each Purpose of Trip
in Cities of Six Population Groups

Population Group (thousands)	Number of Cities	Average Time Parked for Each Trip Purpose—Hours				
		Work	Shopping	Business	Other	All Purposes
	(1)	(2)	(3)	(4)	(5)	(6)
Less than 25	5	3.1	0.7	0.7	1.1	1.1
25-50	3	2.9	0.7	0.8	0.9	1.3
50-100	2	3.3	0.8	0.7	0.9	1.3
100-250	5	4.0	0.9	1.0	1.5	1.7
250-500	3	4.5	1.4	1.2	1.5	1.8
500 and over	2	5.1	1.4	1.4	1.2	2.5

SOURCE: (Same as Table III-1).

Table III-4

PURPOSE OF TRIP OF PARKERS IN BUSINESS DISTRICTS OF 35 CITIES

City	1940 Population (nearest thousand)	Percentage of Parkers Whose Trip Purpose Was—			
		Work	Business	Shopping	Other
Decatur, Ind.	6,000	16	34	23	27
Seymour, Ind.	9,000	13	30	31	26
Columbus, Ind.	12,000	12	36	28	24
Frankfort, Ind.	14,000	15	31	29	25
Huntington, Ind.	14,000	16	37	28	19
Portsmouth, N. H.	15,000	9	24	53	14
Stevens Point, Wis.	16,000	16	27	34	23
Walla Walla, Wash.	18,000	10	39	39	12
Anderson, S. C.	19,000	20	28	42	10
Meadville, Pa.	19,000	20	25	29	26
Lake Charles, La.	21,000	22	35	24	19
Boise, Idaho	26,000	15	29	27	29
Alexandria, La.	27,000	22	25	20	33
Monroe, La.	28,000	22	23	26	29
Easton, Pa.	35,000	13	32	40	15
Anderson, Ind.	42,000	13	37	32	18
Corpus Christi, Tex.	57,000	16	38	26	20
Pawtucket, R. I.	76,000	12	28	49	11
Harrisburg, Pa.	84,000	27	36	19	18
Charlotte, N. C.	101,000	22	37	19	22
Tacoma, Wash.	109,000	12	51	29	8
Reading, Pa.	111,000	21	37	26	16
Knoxville, Tenn.	112,000	13	52	16	19
Wichita, Kans.	115,000	14	39	27	20
Spokane, Wash.	122,000	18	42	23	17
Chattanooga, Tenn.	128,000	18	44	22	16
New Haven, Conn.	161,000	6	48	37	9
Nashville, Tenn.	167,000	18	55	17	10
Honolulu, T. H.	179,000	23	38	17	22
Providence, R. I.	254,000	17	50	23	10
Toledo, Ohio	282,000	20	45	21	14
Atlanta, Ga.	302,000	24	45	18	13
Portland, Ore.	305,000	12	42	22	24
Seattle, Wash.	470,000	15	51	18	16
Baltimore, Md.	859,000	43	31	17	9
Range	.....	6-43	23-55	16-53	8-33
Average	.....	17	37	27	19

SOURCE: Table 140, Traffic Engineering Handbook. Compiled by Bureau of Public Roads from Origin and Destination Surveys.

The trip purpose of vehicle parkers does not make as distinctive a pattern by city size as the previously noted relations, and the ranges of purposes vary considerably among the several cities which have been compared. Type of city, degree of service by mass transit, and other variables are reflected in the percentage of parkers in terms of trip purpose.

Table III-4 provides trip purpose information, for automobile parkers only, in a selected group of cities of various sizes.

Space turn-over is related to parking regulations and trip purpose. Turn-over of spaces provided for GAF sales range from about 3.5 to 4.0 per eight-hour day.

Table III-5 shows how turn-over is affected by regulations.

Table III-5
EIGHT-HOUR TURN-OVER RATE

<i>Parking Period</i>		<i>Average, 8-Hour Turn-over Cars per Stall</i>
Curb	12 Minutes, Metered	10
	30 Minutes, "	14
	60 Minutes, "	9
	120 Minutes, "	5
	12 Minutes, Unmetered	11
	30 Minutes, "	8
	60 Minutes, "	6
	120 Minutes, "	4
	Unlimited	2
	Curb parking—combined	6
Lot	Free	1¼
	Pay	1¼
Garage	Pay	1
	Off Street—combined	1¼

SOURCE: Table 136, Traffic Engineering Handbook, 1950.

The turn-over shown in Table III-5 reflects enforcement practices as well as extent of usage of parking facilities.

To further particularize the estimate of parking in terms of type of generator, studies were made in Baltimore in 1948 and reported by J. Trueman Thompson and Joseph T. Stegmaier.⁷

⁷ Thompson, J. Trueman, and Stegmaier, Joseph T., "The Effect of Building Space Usage on Parking Demand," Bulletin 19, Highway Research Board, 1949.

Table III-6

SUMMARY OF PARKING SPACE DEMAND CREATED ON 24-HOUR WEEKDAY BY VARIOUS GENERATORS AND RELATIONSHIPS WITH FLOOR AREA OR OTHER BASIC UNITS

<i>Generator</i>	<i>Purpose of Trip</i>	<i>Driver Auto Trips^a</i>	<i>Estimated Turnover</i>	<i>Spaces Parking Required</i>	<i>Gross Floor Area or Other Basic Unit</i>	<i>Gross Floor Area or Other Basic Unit per Parking Space Required</i>
Department Store "A"	Work Shop	104	1	104	182,145 sq. ft.	283 sq. ft.
	Other	1,036	2 ^b	518	(selling area)	(selling area)
	Total	62	3	21	305,145 sq. ft.	475 sq. ft.
Department Store "B"	Work Shop	146	1	146	185,000 sq. ft.	518 sq. ft.
	Other	415	2 ^b	208	(selling area)	(selling area)
	Total	10	3	3	245,000 sq. ft.	686 sq. ft.
RR Passenger Station	Total	1,187	1.2 ^c	989	93,583 sq. ft.	95 sq. ft.
Retail and Mail Order Store	Work Shop	286	1	286	1,300,000 sq. ft.	1,816 sq. ft.
	Other	808	2 ^b	404		
	Total	78	3	26		
Neighborhood Shopping Community	Work Shop	294	1	294	120 shops at 5,000 sq. ft. each equals	813 sq. ft.
	Other	582	3 ^d	194	600,000 sq. ft.	
	Total	1,000 ^e	4	250		
General Market	Work Shop	5 ^f	1	5		
	Other	399	2 ^b	200	45,000 sq. ft.	199 sq. ft.
	Total	64	3	21	650 stalls	2.9 stalls
Department Store "C"	Work Shop	144	1	144	100,000 sq. ft.	180 sq. ft.
	Other	735	2 ^b	368		
	Total	134	3	45		
Industrial Plant	Work Shop	447	1	447	1,913,000 sq. ft.	4,223 sq. ft.
	Other	19	3	6	3,138 employees	6.9 employees
	Total			453		
Office Building "A"	Work Shop	313	1	313	591,000 sq. ft.	1,628 sq. ft.
	Other	150	3	50	(net rentable area)	(net rentable area)
	Total			363		
Office Building "B"	Work Shop	292	1	292	252,000 sq. ft.	818 sq. ft.
	Other	49	3	16		
	Total			308		
Theater	Soc.-Cul. & Recreation	205	1.5 ^g	137	50,000 sq. ft.	318 sq. ft.
	Work Shop	20	1	20	3,000 seats	19.1 seats
	Total			157		
Public High School	Work & School	201	1	201	256,400 sq. ft.	1,263 sq. ft.
	Other	7	3	2	1,527 students	7.5 students
	Total			203		
University Campus	School	266	2 ^h	133	398,500 sq. ft.	910 sq. ft.
	Home	283	1.2 ^h	236	(net academic area)	(net academic area)
	Other	60	1	60	613,500 sq. ft.	1,401 sq. ft.
Hotel	Work & Business	100	1 ^k	100	(total area)	(total area)
	Recreation	56	1.4 ^m	40	3,335 students	7.6 students
	Other	61	3	20	4,346 seats	9.9 seats
Bus Terminal	Work & Business	100	1 ^k	100	162,000 sq. ft.	1,013 sq. ft.
	Recreation	56	1.4 ^m	40	425 guest rooms	2.7 guest rooms
	Other	61	3	20	700 capacity	4.4 capacity
Private Hospital	Work, Home & Medical	172	1	172	25,000 sq. ft.	1,042 sq. ft.
	Other	78	2 ⁿ	39	46,000 sq. ft.	1,917 sq. ft.
	Total			211	(incl. garage area)	(incl. garage area)

^a Except those to serve passengers.

^b Low due to peak-hour traffic.

^c Greater than unity due to 24-hour period.

^d Higher due to shorter time parked at specialty shops.

^e Also omits trips "to home."

^f But many workers drive trucks.

^g Low due to evening peak hour.

^h Higher due to evening and night classes.

^k Business not at hotel—actually "to room" purpose.

^m Low due to evening peak hour.

ⁿ Low due to visiting-hour peaks.

Table III-6 is taken from their report and shows for a specific environment (Baltimore, Maryland with a population of 949,708 in 1950) the relations between size and type of generator and its parking demand. This table indicates values of usage including turn-over provided by single establishments. Combinations of several types of generators may require more parking space than the sum of the requirements of the individual components.

An examination of zoning regulations for parking in a particular city will give an indication of the parking activity and traffic generation of various types of generating units. (In some zoning ordinances exemptions are made for specified areas.) A review of the data presented in Bulletin 24, Zoning for Parking Facilities, Section 1, published by Highway Research Board discloses that the following provisions, Table III-7, are being written into zoning laws, or are being suggested therefor.

Table III-7

ZONING PROVISIONS FOR OFF-STREET AUTO PARKING

<i>Unit</i>	<i>Parking Facilities Required (Average)</i>
One and two family dwellings	One space per family dwelling unit
Multiple family dwellings	$\frac{3}{4}$ space per family dwelling unit
Hotels	$\frac{1}{2}$ space per room, plus $\frac{1}{2}$ space for each employee
Tourist Homes, Cabins, Motels	One space for each room, plus one space for manager
Hospitals	$\frac{1}{4}$ space for each patient bed, plus one space for each doctor (based on average number per day), plus $\frac{1}{4}$ space for each employee, including nurses
Sanitariums	$\frac{1}{6}$ space for each patient bed, plus $\frac{1}{4}$ space for each employee, including nurses, plus one space for each doctor (average per day)
Mortuaries	Varies, minimum one space for each resident family, and $\frac{3}{4}$ space for each employee

<i>Unit</i>	<i>Parking Facilities Required (Average)</i>
Welfare Institutions	One space for each doctor associated with institution
Community Centers, Libraries, Museums, Post Offices, Civic Clubs, etc.	Minimum — $\frac{3}{4}$ space for each employee
Dance Halls	One space for each 36 sq. ft. of dance floor area plus $\frac{3}{4}$ space for each employee
Bowling Alleys	One space for each alley, plus $\frac{1}{2}$ space for each employee
Convention Halls, Gymnasiums, Parks, Race Tracks, Skating Rinks, and similar uses	$\frac{3}{4}$ space for each employee, plus such additional spaces for patrons as determined necessary
Theaters	$\frac{1}{4}$ space per seat, plus $\frac{1}{2}$ space per employee
Auditoriums	$\frac{1}{4}$ space per seat, plus $\frac{3}{4}$ space per employee
Stadiums	$\frac{1}{4}$ space per seat, plus $\frac{3}{4}$ space per employee
Churches	$\frac{1}{4}$ space per seat, plus one space for each church official resident on premises, plus $\frac{1}{2}$ space per permanent employee
Office, Professional, or public buildings (A study of 18 generators of this type showed one space required for an average gross floor area of 1,000 square feet, but with a range from 230 square feet to 2,070 square feet)	One space per each separate office, plus $\frac{1}{4}$ space per employee, plus such additional spaces as deemed adequate for visitors
Restaurants, Night Clubs, and Tea Rooms	$\frac{1}{4}$ space per employee plus such additional patron parking as deemed adequate
General Business, Commercial, and Personal Service Establishments	Varies with employees and patrons. Perhaps requirement can be related to volume of sales, or business activities. See previous exposition in this chapter
Industrial or Manufacturing Establishments	$\frac{1}{4}$ space per employee plus additional spaces required in conduct of business

Truck Loading Zones

The greatest truck traffic generated by truck loading zones is found in industrial and distributing areas. Considerable variations exist among various cities with respect to zoning provisions. The following table is indicative of minimum requirements.

Table III-8
SUGGESTED REQUIREMENTS FOR OFF-STREET TRUCK LOADING BERTHS
IN NEW YORK CITY

<i>Manufacturing, storage, goods display, department store, hospital, with floor space in square feet of</i>	<i>Office or hotel for transients, with floor space in square feet of</i>	<i>Number of truck berths required</i>
under 40,000	under 150,000	1
40,000 to 99,999	150,000 to 399,999	2
100,000 to 159,999	400,000 to 659,999	3
160,000 to 239,999	660,000 to 969,999	4
240,000 to 319,999	970,000 to 1,299,999	5
320,000 to 399,999	1,300,000 to 1,629,999	6
400,000 to 489,999	1,630,000 to 1,959,999	7
each additional 90,000	each additional 350,000	1

NOTE: Each loading or unloading berth should be 40 ft. in depth, 10 ft. in width and 14 ft. in height.

SOURCE: Regional Plan Association of New York, with modifications by Nathan Cherniack of New York Port Authority, 1946 Proceedings, Institute of Traffic Engineers.

II. Mode Translation

Air, rail, bus and water terminals provide a translation from these respective modes of transport to the passenger automobile and truck. The number of peak hour passengers appears to provide the best basis for determination of factors and ratios for translating other modes of traffic into automobile traffic.

*Airport Translation*⁸

The Civil Aeronautics Administration in 1949 obtained basic data relevant to developing standards for space requirements at

⁸ Airport Terminal Activities and Space Utilization, U. S. Dept. of Commerce, 1950.

airport terminal areas. Analysis of the data provided factors for determining the correlation between airline passenger activity and automobile traffic.

A basic finding in the study is that practically all major activities at an airport are closely related to the volume of passenger activity. The number of airline passengers at any airport is an item of recorded information and is readily available.

Enplaned and deplaned passenger data by each flight are recorded on "Ground Performance Reports" or similar forms. The Civil Aeronautics Board publishes data regularly in "Enplaned Traffic by Community." From these sources data are available from which the annual total and peak hour traffic can be determined.

Correlations of passenger activity and other major activities indicate that firm estimates can be made by classifying the airports in three groups by passenger activity, i.e., the number of passengers enplaned and deplaned:

1. 1,000 or more passengers per day
2. 200-999 passengers per day
3. 40-199 passengers per day

Estimates within these groups are then related to annual air passengers and the peak hour air passengers. In case of a proposed airport where annual air passengers are estimated, the peak hour passengers may be estimated from the following table:⁹

Table III-9

PEAK HOUR PASSENGERS AS PERCENT OF ANNUAL PASSENGERS

<i>Number of Average Daily Passengers</i>	<i>Low</i>	<i>Median</i>	<i>High</i>
1,000 and up	.032%	.043%	.055%
200-999	.041	.061	.074
40-199	.075	.086	.120

Having obtained either from records or estimates the number of air passengers during the peak hour, the number of cars entering the terminal area during the peak hour may be determined by

⁹ Airline Passengers, U. S. Dept. of Commerce, U. S. Government Printing Office.

multiplying the number of peak hour air passengers by appropriate factors as follows:

Table III-10
CARS ENTERING TERMINAL AREA
(Peak Hour Movement)

<i>Number of Average Daily Passengers</i>	<i>Low</i>	<i>Median</i>	<i>High</i>
1,000 or more	0.8	1.0	1.3
200-999	0.8	1.5	2.0
40-199	1.0	1.5	2.0

Assume an airport with 500 daily passengers and a peak hour of 100 passengers, the peak hour automobile count would be, for median value, about 150. Since the average occupancy of an automobile is approximately two at airports, it is seen that the total number of persons using autos to arrive and depart in this particular activity group is equal to about three times that of the air passengers.

An examination of the statistics compiled for airports operated by the Port of New York Authority disclose the following relations.¹⁰

Table III-11
AIRPORT TRANSPORTATION BY AUTO AND BUS

<i>Airport</i>	<i>Date</i>	<i>Air Passengers</i>	<i>Total Airport Population</i>	<i>Transported by car of total</i>	<i>Coach and Bus of total</i>
La Guardia	7/18/52	13,875	44,307	77.6%	17.2%
N.Y. International	8/1/52	9,127	44,417	79.6%	16.6%

The Houston Municipal Airport with 2,500 daily passenger arrivals and departures in 1954 required 7,200 motor vehicles a day to service the total airport population.¹¹

Bradley Field, Windsor Locks, Connecticut with 660 daily passengers in 1953, required 2,000 motor vehicles.¹²

¹⁰ "Planning Ground Transportation Facilities for New Airport." Louis E. Bender, October 1954 Traffic Quarterly. Eno Foundation, Saugatuck, Connecticut.

¹¹ Report of Eugene Maier, Director, Dept. of Traffic and Transportation, Houston, Texas.

¹² Report of Ernest T. Perkins, Asst. Chief Engineer, Connecticut State Highway Department.

The following table shows parking activities at a selected group of airports.

Table III-12
AIRPORT AUTO PARKING AND CARS ENTERING

<i>Airport</i>	<i>Peak Hour Passengers</i>	<i>Parking Spaces</i>	<i>Peak Parked cars</i>	<i>Percent Utilization of Parking Spaces</i>	<i>Cars Entering Terminal Area During Peak Hour</i>
LaGuardia		1,734	1,540	89	589
Washington	453	477	477	100	—
Los Angeles	353	880	219	25	605
San Francisco	447	NA	310	—	106
Detroit	308	1,500	493	33	242
Dallas ¹	702	234	396	100	113
Atlanta	387	676	300	44	312
Minneapolis ¹	204	700	707	100	555
Kansas City	219	386	334	87	—
Portland	176	250	159	64	106
New Orleans	154	209	170	81	149
Milwaukee	131	1,156	290	25	365
Charlotte	108	290	80	28	76
Columbus	NA	NA	133	—	—
Salt Lake City	121	NA	114	—	114
Omaha	73	956	172	18	358
Oklahoma City	99	250	125	50	131
Baltimore	79	230	198	86	150
Providence	86	160	78	49	46
Birmingham	105	685	188	27	243
Phoenix	59	260	112	43	317
Richmond	69	200	95	48	87
Wichita	45	240	230	96	—
Toledo	36	227	133	59	128
Boise	51	150	79	53	69
Corpus Christi ¹	49	46	47	100	47
Bristol	34	160	62	39	39
Harrisburg	NA	151	100	66	98
Great Falls	22	300	45	15	28
Savannah	25	400	48	12	—
Reading	27	325	190	58	—
Santa Barbara	21	40	20	50	28
Flint	21	175	77	44	70
Lincoln	13	48	28	58	29

¹ "Legal" parking spaces as given in Dallas, Minneapolis, and Corpus Christi.

NA Information not available.

SOURCE: Airport Terminal Activities and Space Utilization, U. S. Dept. of Commerce C.A.A., U. S. Govt. Printing Office, 1950.

Airport Parking

One and one-half to two spaces are required for each *peak hour* passenger.¹³ Airports with 1,000 passengers a day will require up to 300 parking spaces. The average duration of parking for all purposes is about one and one-half hours. Cars using parking lots average three occupants. Flow of traffic to and from an airport depends upon flight schedules. The peak movement, however, will probably be during the morning and evening rush hours, resulting from employee transportation.

Rail Translation

The following data indicate the relation between city population, rail passengers and motor vehicle requirements at rail terminals.

<u>City</u>	<u>1950 Population</u>	<u>Daily Rail Passengers</u>	<u>Daily Motor Vehicles (1954)</u>
Washington, D. C.	802,178	50,000 ¹	16,000
Cleveland, Ohio	914,808	Unknown	16,795
Houston, Texas	596,163	1,100 ²	1,275
Phoenix, Arizona	106,818	200	1,200

¹ Includes through passengers, total unknown.

² Southern Pacific Station only.

It is patent that the number of vehicles required to convey passengers depends upon the ratio of taxis to private vehicles, and the loading practices used at the depot with respect to taxis. In Washington, D. C. nearly 25 percent of the motor vehicles are taxis and they are loaded as fully as possible by a dispatcher. This practice is not followed in most cities.

¹³ U. S. Dept. of Commerce, op. cit.

SELECTED REFERENCES FOR SUPPLEMENTAL READING

1. Traffic Engineering Handbook, 1950. Chapters 6 and 10. Institute of Traffic Engineers, Washington, D.C.
2. Bulletin 19, *Parking*. Highway Research Board, Washington 25, D.C., 1948.
3. Bulletin 24, *Zoning for Parking Facilities, Section 1*. Highway Research Board, Washington 25, D.C. 1950.
4. Bulletin 59, *Zoning for Truck-Loading Facilities*. Highway Research Board, Washington 25, D.C. 1952.
5. Bulletin 64, *Highway Planning and Urban Development*. Highway Research Board, Washington 25, D.C. 1952.
6. Hitchcock, S. T. *Influence of Population, Sales and Employment on Parking*. Vol. 32, Proceedings, Highway Research Board, 1953.
7. *Airport Terminal Activities and Space Utilization*. U.S. Department of Commerce, Civil Aeronautics Administration. U.S. Government Printing Office, Washington 25, D.C. July 1950.
8. Airports and Air Traffic in the New York Area. Madigan-Hyland, Engineers, New York City. 1946.
9. Air Traffic Forecast, New York-New Jersey Port District, 1950-1980. The Port of New York Authority, New York City. June 1950.
10. Bender, Louis E. *Planning Ground Transportation Facilities for New Airport*. Traffic Quarterly, October 1954. Eno Foundation, Saugatuck, Conn.
11. Traffic Engineer's Technical Notebook, Institute of Traffic Engineers, Washington, D.C.
12. Bulletin 99, *Parking Requirements in Zoning Ordinances*. Highway Research Board, Washington 25, D.C. 1955. (A Supplement to Bulletin 24).
13. *Shopping Habits and Travel Patterns*. Special Report 11-3, Highway Research Board, Washington 25, D.C. 1955.
14. New York's Air Travelers. The Port of New York Authority. Eno Foundation. 1956.

CHAPTER FOUR

DISTRIBUTION OF TRAFFIC

Purpose of Distribution Estimates: Estimates of traffic distribution are usually made to determine probable usage of proposed traffic arteries and the resultant effect upon adjacent arteries. This estimate of usage is commonly called *traffic assignment*. Estimates of distribution may also include a forecast or projection of future usage. Methods of forecasting are considered in Chapter V.

Items of Estimate: Estimates of traffic volume changes are usually made by an analysis of origin and destination studies and are usually expressed in terms of the annual average daily traffic volume and its composition by type of vehicle. Factors are applied to this value to obtain the design hour volume, periodic direction pattern, and interchange turning movement. Composition is expressed in terms of the average week-day pattern.

Components of Distribution: When estimates are made to indicate results of changes proposed in the highway or street system, the following components of traffic are evaluated:

1. Traffic diverted from existing alternate routes, related to trip purpose.
2. Traffic converted from one mode of transportation to another.
3. Traffic induced or "released" by expansion of capacity and adequacy of system.
4. Traffic created by the new facility itself, acting as a traffic generator or magnet, thus in effect being the destination of one trip and the origin of another. Drivers who go to see the facility itself compose the component.
5. Traffic shifted due to a change in origin or destination.
6. Traffic translated, involving a change in mode of travel en route between origin and destination.

These six items will provide an estimate for the immediate future. Ordinarily, the traffic analyst will project the usage into the future, adding a component for land development.

Traffic growth in time will affect each of the above factors, though not necessarily to the same degree. See Chapter V.

Uses of Estimates: Estimates of distribution, or traffic assignment, are fundamental to the following determinations:

1. Determination of traffic flow pattern and operational character of new facility and resultant effect on flow pattern and operation in area of its influence (i.e. relief to parallel arteries and encumbrance of interchange distributors).
2. Comparison of service and economy of proposed alternate routes and resultant effects area-wise, as a guide in the selection of the most desirable route, or combination of parts.
3. Selection of geometrical and structural design standards for the facility proper and its appurtenant interchanges and terminals.
4. Advance planning of traffic control and regulation for facility with its appurtenances, and of the area to be served by the facility.
5. Economic appraisal (free and toll facility):
 - a. cost of provision, maintenance and operation; b. user benefits derived in time and distance saved; c. revenue derived from user tax and toll; d. determination of optimum toll schedule, amortization periods, and coverage.

The economic appraisal evaluates feasibility in terms of benefit-cost ratio (benefit quotient) and also revenue-cost ratio (solvency quotient). For the toll facility it provides for a determination of economic feasibility in terms of coverage for the period of amortization, expressed in terms of average annual net revenues divided by average annual costs. A coverage of from 1.25 to 1.50 or higher is usually sought when financing is entirely by revenue bonds.

Considerations in Route Selection: Inasmuch as the location for a new route and an estimate of traffic thereupon are mutually dependent, a change in one may be reflected in the other. In order to obtain the maximum benefit in the provision of additional traffic arteries the following desirable criteria will serve as a guide in the selection of the location of new facilities. Maximum benefit will accrue:

1. Where the trip frequency between origin and destination via the subject facility is the greatest.
2. Where the trip transfer (between origin and destination) via the proposed facility is most economical, and greatest benefit accrues to user.
3. Where trip frequency and trip length (between origin and destination) combine to create greatest vehicular mileage and consequently the greatest revenue.
4. Where the least amount of adverse travel occurs.

5. Where relief afforded inadequate competitive facilities is greatest, in other words, where greatest amount of diversion will occur.
6. Where the service afforded to the whole area under consideration is greatest, and the most vital part of the problem is solved.
7. Where induced traffic is greatest.
8. Where land-development traffic is greatest.
9. Where location is physically best for requirements in system connections and traffic operations.
10. Where cost of provision, maintenance and operations is lowest.
11. Where the resulting economic and social changes are the most desirable.

It will be recognized that no single location can be chosen that will fulfill the demands of all of these criteria, for it is seen that some criteria may in application oppose others. For example, the location which provides the greatest user benefit may not at the same time provide the greatest revenue, and the location which will afford the greatest relief to existing traffic may not bring about the greatest land development, although both of these are possibilities. Each of the criteria should be considered, however, for each proposed location in the light of the purpose of the improvement and of the major problem existing, and a balance obtained, as far as possible, in satisfying each of the criteria.

In the end, if the location is to be a free facility, the benefit-cost ratio may be a significant factor, but if it is to be a toll facility the revenue-cost ratio may be the determinant. In calculating the benefit-cost ratio or revenue-cost ratio, the complete trip from origin to destination should be considered as well as the part of the trip made on the proposed facility itself.

It should be pointed out that a bridge might be justified on the basis of revenue-cost ratio from zone of origin to zone of destination rather than from one end of the bridge to the other. In fact, this premise is illustrated when one pays toll to use a bridge: he pays in order to get from origin to destination rather than to merely cross the bridge.

Concept of Distribution: In its flow between pairs of zones of origin and destination, the traffic stream distributes itself among the available arteries forming connecting links between the

paired zones in accordance with certain principles which seek to bring about an equilibrium of forces. A change, whether in traffic volume, mode of travel, or in location or capacity of arteries, will cause a redistribution of flow among the several arteries in order to regain a state of equilibrium in volume and mode. In other words, traffic seeks its own level much the same as water.

In seeking its own level, or in the establishment of equilibrium, traffic, in its flow through arteries which offer various magnitudes of resistance, tends to seek economy of energy, or the path of least action. It is easily understood that as volumes change between zones the relative resistance changes among the connecting arteries and the energy of flow varies accordingly. The relative resistance to flow is affected by the transmission quality of an artery and by traffic itself.

Influence Factors: a) Transmission quality¹ is an influence factor in distribution. The transmission quality of an artery is influenced by several of its distinguishing characteristics, namely,

1. Geometric design
2. Condition of surface
3. Access
4. Control devices and markings
5. Regulations (speed, direction, turns, parking, size, weight, etc.)

b) The operational characteristics of the traffic stream provide other influence factors in distribution. Significant among these characteristics which are interrelated to some degree, are:

1. Continuity of motion
2. Differential speed
3. Spacing (density)
4. Lateral placement

Bruce D. Greenshields² has proposed a measure of traffic transmission in which the traffic stream is characterized by its quantity and quality of flow.

¹ The expression "transmission quality" was used by the late T. M. Matson of the Yale Bureau of Highway Traffic in referring to the capacity characteristics of a traffic artery.

² *Quality of Traffic Transmission*. Bruce D. Greenshields. Proceedings, 34th Annual Meeting, Highway Research Board, Washington 25, D.C. 1955.

Quality of flow is expressed by the formula:

$$Q = \frac{KS}{\Delta s f^{1/2}}$$

in which:

- Q = quality index
- K = constant (1000 is suggested by Greenshields)
- S = average speed of traffic stream
- Δs = sum of speed changes per mile
- f = frequency of speed changes per mile

Quantity of flow is expressed by the formula:

$$\text{Quantity} = Vm$$

in which:

Vm = Vehicles per mile per hour on a unit area one mile long and ten feet wide

Efficiency of flow is expressed by the formula:

$$E = VmQ$$

in which:

- E = Efficiency index
- Vm = quantity index, and
- Q = quality index

c) Trip purpose or motivation of the trip provides further influence factors in distribution.

Significant in motivation, or trip purpose, are:

1. Work
2. Business
3. Shopping
4. Social-Recreational
5. Eat Meal
6. Serve passenger
7. Home
8. Migration, etc.

d) Length of new facility, length of trip, frequency and urgency, knowledge of route, relative safety, and schedule of tolls (if toll facility) provide additional determinants in the pattern of distribution. Driver psychology should also be included.

It is believed, for example, that force of habit is a significant factor in choice of travel route. Freedom from restraint and fear, provided by freedom of movement, the "breathing space" which permits a choice of speed, is another. When the density of traffic confines the driver to the speed of the stream and he is unable to move out of his lane to pass, then even an 8-lane expressway may be unattractive. When the ability to keep moving is hindered, the driver seeks a more fluid route.

I. Traffic Distribution on Free Roads

Development of Empirical Method: With many factors contributing to the pattern of distribution, attempts to establish a statistical model have not thus far obviated the use of judgment. Qualitative evaluations of the various influence factors have been determined rationally but quantitative values have not been determined empirically to a degree of accuracy that permits their use in a distribution formula.

In view of the complexity of establishing a statistical model, explorations were made to determine whether there are any dominant influence factors which maintain a constant relation to the pattern of distribution, or whose effects are reproduced with little deviation regardless of time or place. Such dominant influence factors could then serve as an index.

In the search for a method of distribution or assignment it was recognized that an objective measurement of the mass movement was desirable in order to provide a practicable tool. Measurement in the mass assumes a somewhat constant array of distribution influence factors: trip purposes, speeds, freedom of movement, continuity of motion, frequency of trip and other components of a given quality of transmission. Subjective choice of route made by the motorist is often the result of "sensing" rather than analysis and the motorist is not always able to give a precise reason for his choice of route.

But day by day, the pattern of distribution remains consistently stable. From this premise—stability of pattern—confidence was derived to seek a dominant influence factor to serve in an index

of distribution. As a practical matter it is desirable that the factor to serve in an index should be one that can be measured objectively and quantitatively in a relatively simple manner.

Judgment, coupled with previous experience in analyzing traffic behavior suggested several dominant influence factors, including relations of transmission quality and environment with trip travel time and with trip travel distance. Research into these relationships indicated that the factor of trip travel time as a dominant influence factor satisfied the conditions of an index under given conditions of transmission quality. Travel distance has also been found to serve as a satisfactory influence factor under certain conditions.

Diverted Traffic: Several urban arterial route studies have been initiated to determine the amount of traffic that will be attracted (including diverted, converted, shifted, and translated traffic) from existing routes to new arterials in urban areas. Upon completion, the results of each study were forwarded to the Bureau of Public Roads at Washington, D. C. for correlation and summarization. Eight studies of this nature were analyzed as shown in Figure IV-1 and a report prepared covering the findings.³ The report states that "travel-time ratio appears to be an excellent common denominator which reflects not only the effect of travel time on the usage of arterial highways but also the effect of other factors as well."

In consequence of the findings from these eight studies, the subcommittee on Factual Surveys of the American Association of State Highway Officials at their 1952 annual meeting adopted a report entitled "A Basis for Estimating Traffic Diversion to New Highways in Urban Areas." The following excerpt and Figure IV-2, titled "Traffic Diversion Curves for Urban Arterial Highways" are taken from the report.

Many factors may influence motor vehicle drivers in choosing a route of travel in urban areas. Travel time, travel distance, ability to keep moving, safety, convenience, habit, and other factors may enter into the choice. Several of these are intangible, however, and their individual effect is difficult if not impossible to evaluate. To be of practical value for purposes of traffic

³ Report of F. N. Barker, Chairman, Factual Survey Committee, AASHO, Dec. 1, 1952.

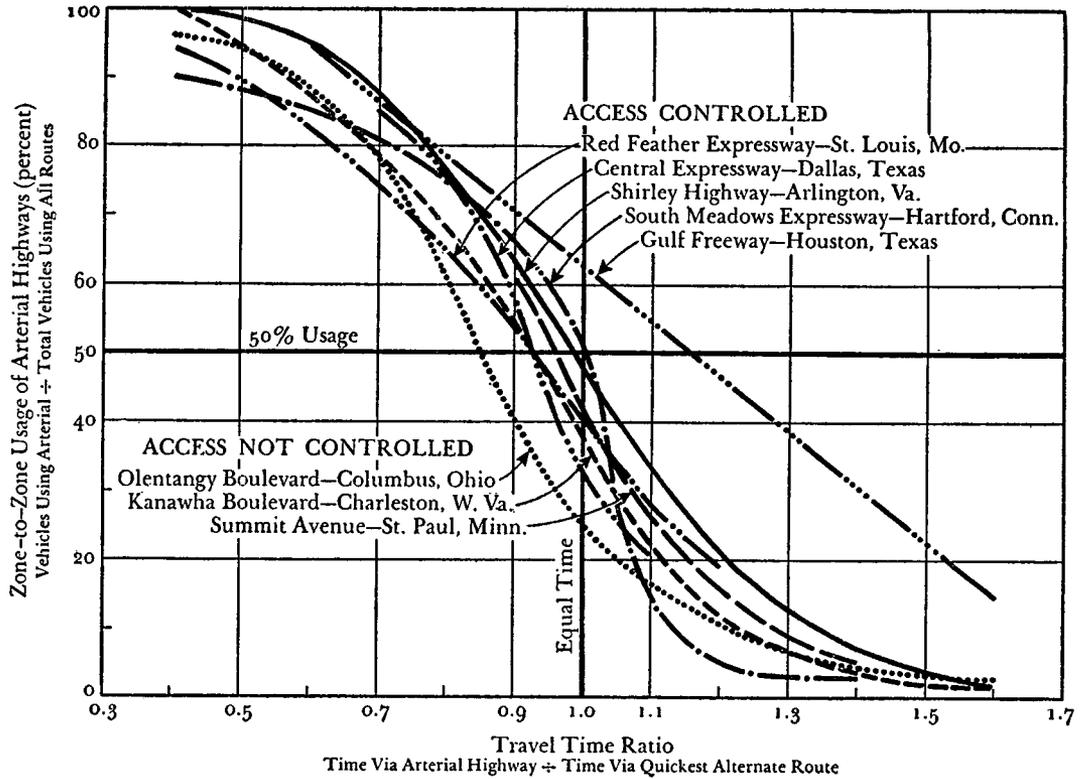


FIGURE IV-1. Traffic diversion curves for urban arterial highways.

SOURCE: Bureau of Public Roads.

assignment, a relation must be established between a tangible factor of influence (one that can be measured quantitatively in a relatively simple manner) and the usage of urban arterial highways.

The first two factors mentioned, travel time and travel distance, qualify in this respect better than any of the others. Either can be ascertained with reasonable accuracy on any route—even on a projected route not yet constructed. For this reason, travel time and travel distance were selected for initial exploration and their relation to the usage of the routes chosen for study was determined in each case.

The general procedure used in collecting data for this research consisted of subdividing the urban areas into zones and obtaining from comprehensive origin and destination surveys the total number of vehicles moving between zones by all routes of travel. The number moving between zones via the arterial highway selected for study was determined from roadside interviews made at appropriate locations along that route.

The percentage of the total traffic moving between various pairs of zones that used the selected route was determined from these data. Travel times and distances were measured for the selected route and for all logical alternate routes between the same pair of zones. The zone-to-zone percentages of use thus obtained for the route in question were then related to the appropriate zone-to-zone travel time and distance measurements.

Several different relations involving travel time, travel distance, and percentage use of the routes selected for study were examined. The curves developed for any given relation varied but little from one study to another, and the relation that proved best in one was best in all other cases as well.

Results

Significant relations developed in these research studies are summarized as follows:

1. A definite relation exists between the usage of an urban arterial highway and the ratio of travel time via that route to the time via an alternate route.
2. A definite relation also exists between the usage of an urban arterial highway and the actual number of minutes saved or lost by using the arterial instead of an alternate route.
3. While a relation exists between the usage of an urban arterial highway and travel-distance ratios the variation is greater than with travel-time ratios, especially when the distance via the arterial is approximately equal to or slightly greater than the distance via an alternate route.
4. Combinations of travel-time and travel-distance ratios show less satisfactory correlation with the usage of an urban arterial highway than do travel-time ratios alone.

It is evident from the data collected and analyzed in these research studies that travel-time ratios provide a reliable basis for making traffic assignments to new arterial highways in urban areas, and that the time-ratio, percentage-use relation is better for this purpose than any of the others investigated. The data show, however, that a single curve for all types of arterial highways is not adequate.

The travel-time ratio curves, when segregated according to the class of highway studied, fall into two rather well-defined groups—one representing freeways⁴ and the other major streets.⁴ Furthermore, with one exception, the curves representing data from the separate studies in each group fall within a close range throughout their entire length. Other than this one exception, the greatest divergence of any individual freeway curve from the average of all in that group, in terms of percentage use, is generally less than ten per cent. The divergence of the major street curves from the average of all in that group is no greater.

The similarity of the individual curves is especially significant since the routes studied were located in different cities, in different parts of the country and were, no doubt, affected by different local influences. This similarity emphasizes the soundness of travel-time ratios as a basis for assigning traffic to arterial highways in urban areas. While it is possible that future studies may indicate the need for some adjustment of the average curve for each group, it is unlikely that the adjustment will be great.

The attached chart (Figure IV-2) shows the average curve for each of the two groups. The upper curve, showing 48 percent usage when travel time by the arterial highway is equal to that by the quickest alternate route, should be used for assigning traffic to urban arterial highways planned as freeways.

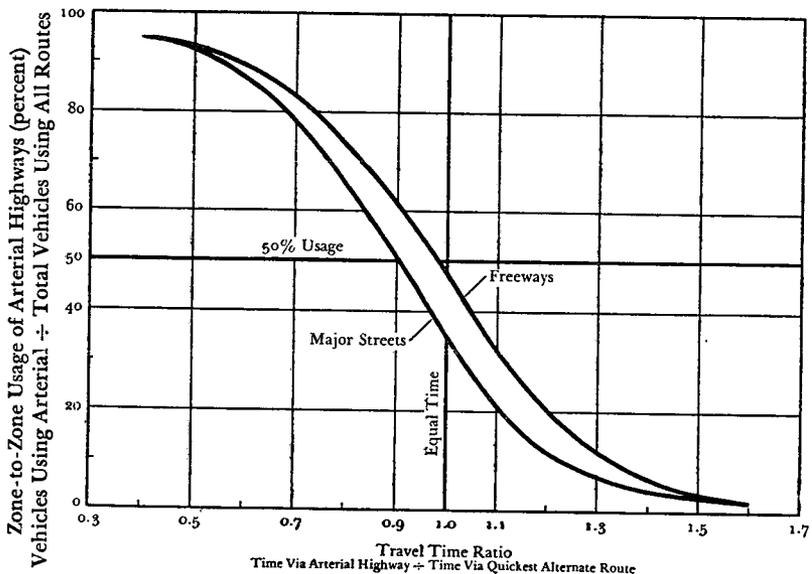


FIGURE IV-2. Traffic diversion curves for urban arterial highways.

SOURCE: A.A.S.H.O.

⁴ Highway definitions prepared by the Special Committee on Nomenclature and adopted by the American Association of State Highway Officials on June 25, 1949.

The lower curve, showing 35 percent usage when travel time by the arterial is equal to that by the alternate, should be used for improvements planned as major streets.

These curves show a range in percentage use for either freeways or major streets, the percentage use of either type of facility varying with the travel-time ratio on the basis of an "S" curve. The "S" curve for freeways holds above the one for major streets at every point except the extreme ends where the two curves coincide. At the upper extreme, when travel time via the arterial highway is 0.4 of that via the quickest alternate route, 95 percent of the drivers will use the arterial facility. At the other extreme, even when travel time via the arterial is 1.6 times that via the alternate, two percent of the drivers will still use the arterial facility.

When travel time by the arterial highway is equal to that by the alternate route, approximately one-half of the drivers will use a freeway improvement or one-third a major street improvement, notwithstanding that in both cases additional distance must be traveled to do so. It is evident from these curves that some drivers prefer to use the arterial highway even at the expense of both time and distance, while others avoid it although both time and distance may be saved.

The findings reported herein pertain strictly to diverted traffic—that is, traffic which will shift from existing streets to a new arterial highway. It is recognized that traffic will also be "generated" by a new highway; however, it is recommended that the attached chart concerning traffic diversion curves for urban arterial highways be used in connection with current traffic assignment work.

An equation which approximately describes the freeway time-ratio diversion curve is: $\text{usage} = \frac{1}{1 + T^6}$, in which T = time ratio and usage is expressed in percentage.⁵

Diversion curves conform to the concept that an arterial shares traffic with alternate routes in proportion to their relative attractiveness, and is not likely to attract all of the traffic between any pair of zones until the advantage in terms of travel time ratio is about 0.4, whence the distance ratio is likely to be less than 1.0.

The curves shown in Figure IV-3 can also be used in estimating diversion to a freeway from an alternate route. The lower curve, identical to the freeway curve in Figure IV-2, can be used to determine the percent diversion to the freeway for any travel-time ratio. The upper curve gives a direct percentage estimate of traffic remaining on the alternate route when the travel-time ratio is calculated as the time on the alternate route divided by that on the freeway.

⁵ Equation proposed by Mr. H. H. Weaver, Indiana State Highway Commission.

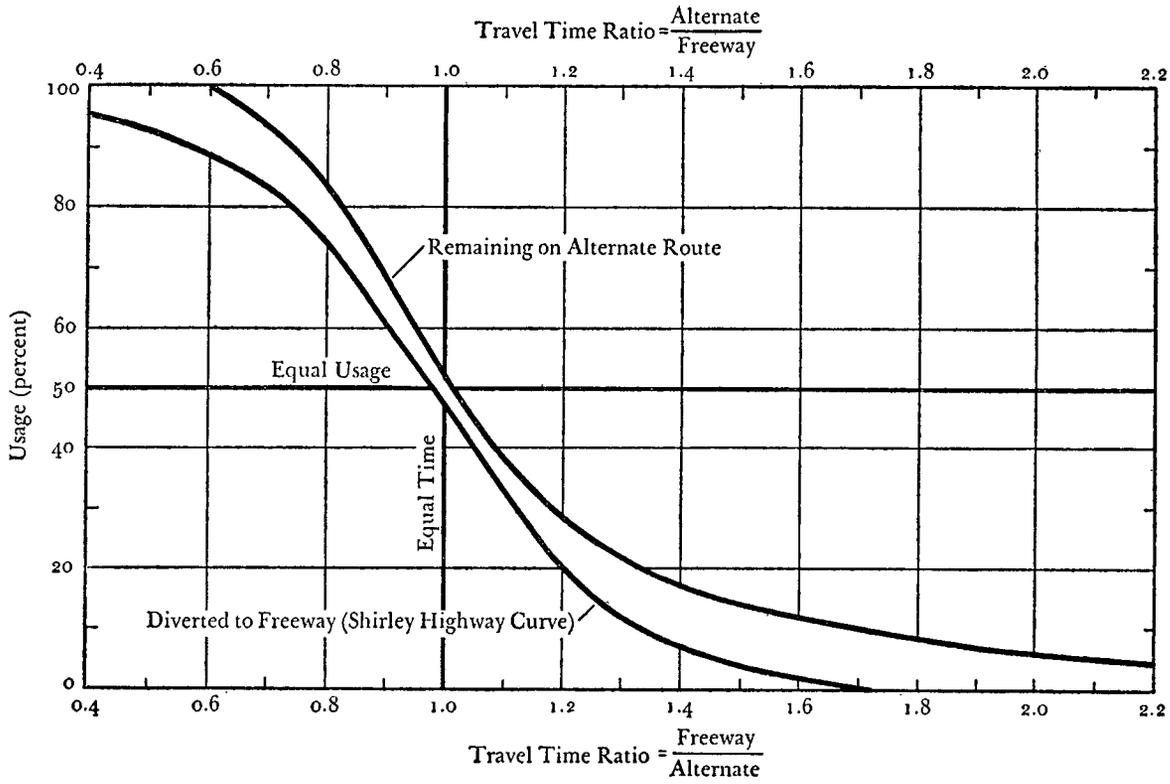


FIGURE IV-3. Comparative usage of Freeway and alternate route for same relative travel time.

With further reference to the two diversion curves in Figure IV-2 it should be pointed out that each of the curves portrays the relation of its respective type of facility to the existing street system. While this is true, there is an indication that the usage curve of the controlled access highway may deviate 10 percent above the usage curve of the boulevard between the ratios of 0.85 to 1.15, and is about thirty-five percent more attractive than the boulevard at equal travel times.

"All or None" Concept: Another method used to some extent in estimating the probable diversion consists of allocating all or none of the traffic between a pair of zones to a new facility depending upon whether the travel time by the new facility is less or greater than by alternate routes. If there were uniform density of population to draw from on each side of the new facility and a homogeneity in land use throughout the area of influence, the results obtained by the "all or none" method could closely approach the results obtained by using the diversion curves. Tests have indicated that the all or none method produces inaccurate estimates, particularly for ramp capacity.

The following comparison will serve to illustrate the differences possible to obtain by the two methods:

<i>Paired Zones</i>	<i>Transfer Volume</i>	<i>Time Ratio</i>	<i>Percent of Diversion by AASHO Curve</i>	<i>Volume Assignment By Curve</i>	<i>Volume Assignment by "All or None" Method, at Time Ratio = 1.0</i>
A-B	100	1.1	33	33	—
B-C	200	0.9	62	124	200
C-D	50	0.6	89	45	50
D-E	300	0.8	74	222	300
E-F	100	1.2	20	20	—
TOTALS	750			444	550

Evolution in Diversion Curves: A time ratio diversion curve developed from a study⁶ in Detroit, where the Willow Run Ex-

⁶ *Objective and Subjective Correlates of Expressway Use.* E. Wilson Campbell and Robert McCargar, Detroit Metropolitan Area Traffic Study. Bulletin 119, Highway Research Board, Washington, D.C. 1955.

pressway was in competition with Michigan Avenue and city streets, showed that fifty percent diversion to the expressway occurred at a ratio of 0.78, and eighteen percent diversion occurred at a ratio of 1.0. The Detroit diversion curve is shown in Figure IV-4.

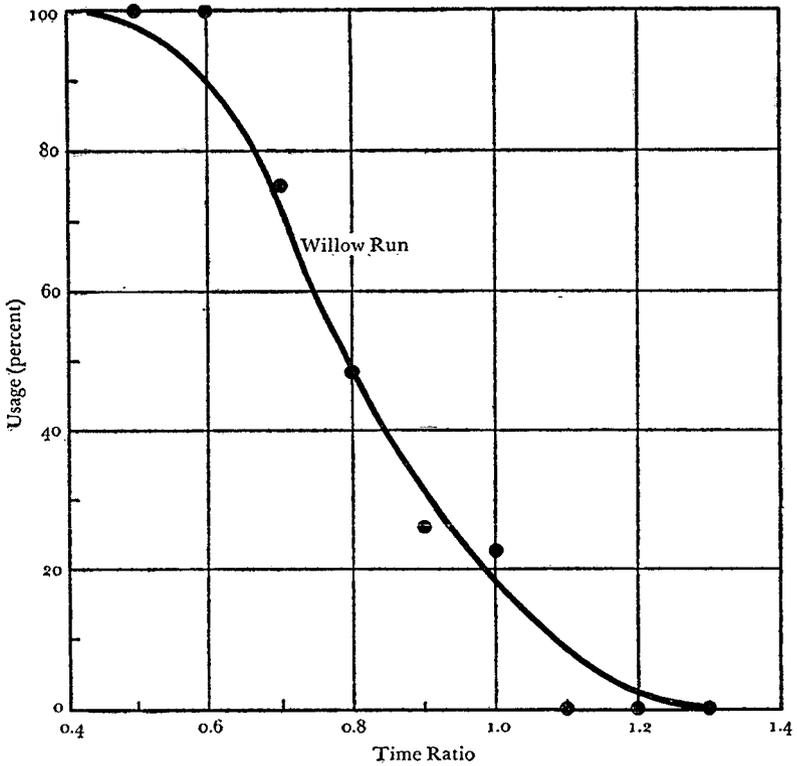


FIGURE IV-4. Curve for Expressway usage in relation to time ratio.

SOURCE: Detroit Metropolitan Area Traffic Study.

Finding that the time-ratio diversion curve derived from the Willow Run study differed so greatly from the AASHO time-ratio diversion curve, the Detroit study was extended to include distance-ratio curves and also indifference curves related to absolute time and distance differentials shown in Figure IV-5.

To determine the effect of a two-variable relation combining measurements which could be easily adapted to mechanical assign-

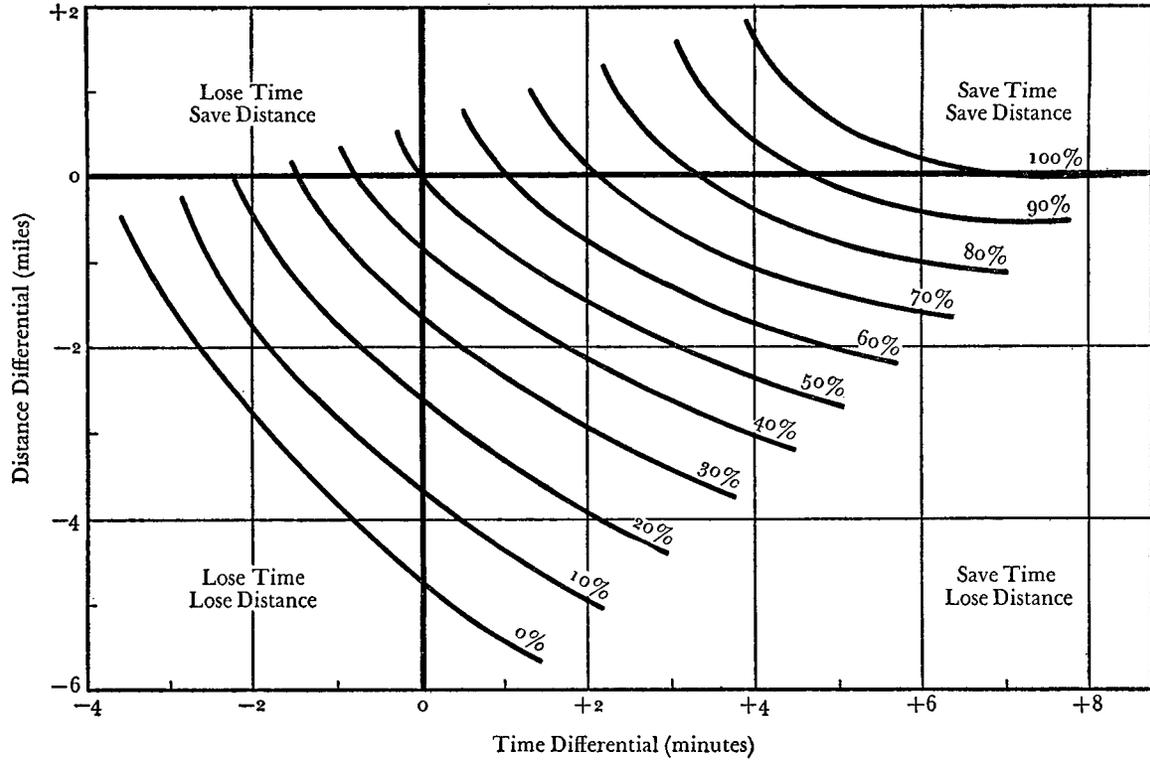
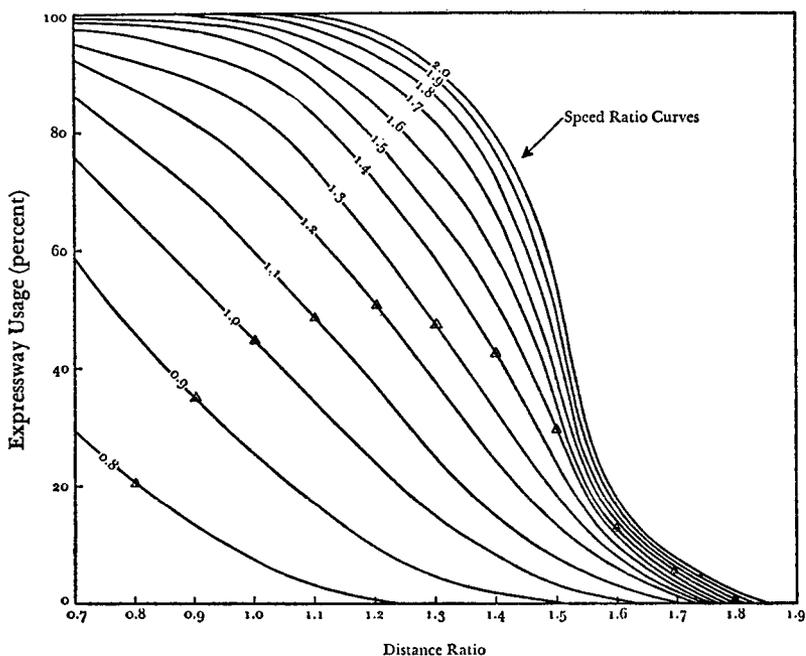


FIGURE IV-5. Indifference curves for various percentages of expressway use, based on time and distance differentials.

SOURCE: Detroit Metropolitan Area Traffic Study.

ment it was decided to use a combination of speed and distance ratios—See Figure IV-6. Tests for accuracy on one case study (Shirley Freeway) gave an assignment of 101 percent of observed volume, with a standard error of ± 9.54 percent for ungrouped data. Ninety-five percent of all individual zone-to-zone transfers were within fifteen percent of the observed volumes.



▲ Indicates points where speed and distance ratio combinations are equivalent to a time ratio of 1.0

FIGURE IV-6. Expressway usage as related to speed and distance ratios.

SOURCE: Detroit Metropolitan Area Traffic Study.

Values derived from Figure IV-6 were adapted to machine assignment and estimates made for the proposed Detroit Expressway System.

From findings reported in the Detroit study, the following conclusions may be made:

1. Expressway users consider time savings to be more important than distance savings.

2. Drivers' attitudes and perceptions do affect their choice of a route. However, objective factors account for most of the variation in behavior. There apparently is no need for including the influence of subjective factors in the assignment of traffic to a proposed expressway.
3. An assignment of traffic to an expressway based on time ratio necessitates a classification of the expressway being appraised and selection of an appropriate time-ratio curve. Volumes assigned to an expressway by a time-ratio curve could vary almost 100 percent depending on which curves were selected.
4. An assignment based on time differential would vary even more than assignment by time-ratio curves. Thus to assign by time differential involves a more careful appraisal and curve selection than for the time-ratio method. In addition to the difficulty of selecting a curve for either time ratio or time differential, it would be difficult to estimate travel times on expressways and city streets some twenty years in the future.
5. Distance ratio appears to be better adapted to assignment than any other single variable curve. A curve made from averaging distance-ratio curves from six expressways assigned to five out of six expressways within \pm five percent of total volume. However, there is considerable variation around the mean percentage values for distance ratio. Probably the average distance-ratio curve would give an assignment within tolerable limits to any single urban expressway having average trip length, time ratio, distance ratio, and speed ratio within the range of values found for the six expressways studied in this report. The distance-ratio method offers the additional advantage of accurate and simple measurement.
6. An expressway network accommodating longer trips and higher speeds requires an assignment by a series of curves employing two variables, so that a variable percentage can be assigned whenever advantages and disadvantages accrue to particular trips. To represent the complexity of the behavior with a single curve is an oversimplification, and if used uncritically could lead to serious errors in assignment.

7. The two variable distance-speed ratio curves appear to offer a simple, fast and accurate method of assignment.

These speed-distance ratio curves were used in assignments to an expressway network in Detroit and proved quite satisfactory. Through a mechanical procedure developed by the Study Staff an assignment of 25,000 transfers to a network of 260 miles of expressways was completed in less than three weeks.

Turning from the Detroit study to California, a memorandum from George T. McCoy to the district engineers and heads of department of the division of highways, California Department of Public Works, under date of April 27, 1954 reads:⁷

II. Traffic Assignment and Road-User Economic Studies

For your information and guidance, this letter sets forth a new method for estimating traffic volume based on origin and destination surveys, and new values for use in economic computations of road-user benefits. This method and these values are to be used for traffic assignment and economic comparisons of alternate routes, particularly for route determinations in project reports.

To secure uniform application of these instructions, you are requested to obtain Headquarters Traffic Department approval of proposed procedures before beginning studies of this nature.

Assignment of Traffic to Freeways

Attached is a chart for the purpose of estimating the volume of traffic which will be diverted to a freeway when the number of trips between given points is known. Until more experimental data are analyzed, and with two exceptions, this chart will be used instead of the previous method of assigning all or none on the basis of "least cost" at 3 cents per mile and 2 cents per minute. The two exceptions are:

1. Through-traffic movements between both ends of a freeway by-pass should be assigned 100 percent to the freeway.
2. If trucks are assigned separately from autos, they may be assigned "all or none" on the basis of travel time via each route. For this purpose, truck travel time should be determined independently of auto travel time. Unless trucks constitute an especially significant segment of the total traffic, it is not required that they be assigned separately.

⁷ In granting permission to publish this memorandum, Mr. McCoy advised that the chart had been developed from empirical values from a limited number of studies and was of a tentative nature until proved by additional experience.

Vehicle Operating Costs

1. Passenger vehicles

Attached is one copy of a report on "Road User Benefit Analyses for Highway Improvements" published by AASHO. Only one copy is being sent because of a limited number available for distribution.

Because of the rise in the cost of operating motor vehicles in recent years, it is deemed advisable to revise the basis for computing user costs from the 3 cents a mile and 2 cents a minute we have been using for some time. Rather than use the unwieldy number of cost figures in the AASHO report, it is suggested that passenger vehicle operating costs of 4.5 cents per vehicle-mile for freeway operation and 4.75 cents per vehicle-mile for city street travel be used. The 4.5 cents per mile is the cost developed in the AASHO report for free operation on tangent divided highway at 52 miles per hour. This condition is a close approximation to freeway operation. The 4.75 cents per mile, which includes 1.0 cent for lack of comfort and convenience, is the average operating cost for restricted operation on two-lane tangent highways at speeds from 20 miles per hour to 32 miles per hour. The cost figures for speeds of 36 and 40 miles per hour were not considered inasmuch as such speed would be unlikely to occur for a restricted type of operation.

2. Trucks

In a review of a 1953 revision of Public Utilities Commission Case No. 4808, it is found that truck costs are about 40 percent higher than the 1948 figures for mileage, but about the same for hours. Therefore, values of 14 cents per mile and 5 cents per minute are recommended as the average for all trucks having more than 4 tires (2-axle with dual tires on rear axle, and heavier). Four-tire trucks (pickup and panel delivery) should be classified as passenger vehicles for economic calculations.

3. Summary

The following values will be used until further notice:

	<i>Per Mile</i>	<i>Per Minute</i>
Passenger cars, freeway	4.5¢	2.6¢
Passenger cars, city streets	4.75¢	2.6¢
Trucks (dual tires and up)	14.0¢	5.0¢

Unit Cost of Traffic Service

In addition to the conventional computation of road-user benefits, it is requested that the unit cost of service be computed for each alternate proposal which is analyzed in the project reports. This cost is defined as the construction and right-of-way cost divided by the vehicle-miles which will be removed from existing roads and streets during a 20-year period following completion of the project.

IBM Calculations

In three recent studies, the Highway Planning Survey has performed the detail calculations of (1) assignment by percentage formula, (2) vehicle-miles and vehicle-minutes for each alternate and for basic conditions, (3) vehicle-miles remaining on existing roads for each alternate, and (4) turning movement volumes at each ramp on each proposed freeway. Data submitted by the District were essentially only the number of miles between zone centroids, first by the basic street pattern and second, by each freeway line. Since this process is just now being developed we are not ready to detail it in writing at this time. However, Headquarters Traffic Department will be glad to explain the necessary steps in this labor-saving process while making the preliminary review of individual studies as they come up.

G. T. McCoy
State Highway Engineer

System Distribution: At this date no study has been made to determine the effect of two comparable boulevards in competition with each other and the alternate city streets, nor has a study been made to determine the effect of two comparable expressways in competition with each other and the alternate city streets.

Figure IV-7 illustrates the type of diagram that might result from a study of two expressways in competition with each other and with alternate city streets. The family of curves suggests the relationships when Expressway One in competition with alternate through-city streets $\left\{ \text{Ratio} = \frac{\text{Expressway One}}{\text{City Street Alternates}} \right\}$ finds additional competition when Expressway Two is located within the area of influence of Expressway One and the through-city streets $\left\{ \text{Ratio} = \frac{\text{Expressway Two}}{\text{City Street Alternates}} \right\}$

Figure IV-7 presents a hypothesis and is not intended to present precise values. Empirical values await field studies of these relationships.

The basis for the family of curves shown in Figure IV-7 rests on the assumption that Expressway Two may be likened to a star number two entering the field of gravitation of an identical star number one with its satellite. Thus, the gravitational limits of star number one range from 0 percent at time ratio of 1.6 to 100 percent at time ratio of 0.4. As the other star approaches the

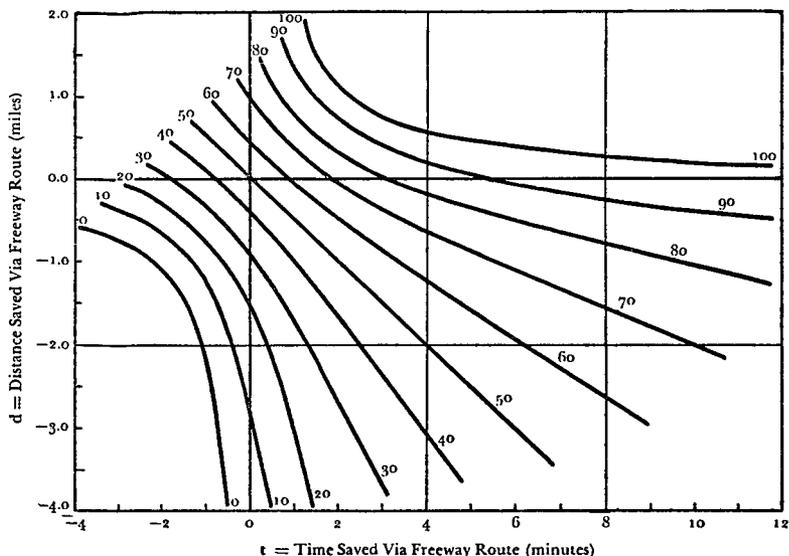


FIGURE IV-6a. Percent of traffic diversion to Freeway in relation to time and distance saved.

Procedure for Use of the Chart:

1. Determine distance between points by best available freeway route (d_f) and by best available alternate route (d_a). The distance saved, d , is d_a minus d_f .
2. Determine travel time between points by best available freeway route (t_f) and by best available alternate route (t_a). The time saved, t , is t_a minus t_f .
3. Enter chart at appropriate values of d and t and read p , the percentage of trips between the given points which will use the freeway route.
4. Multiply p by the number of trips between the given points. Assign this number of trips to the appropriate portion of the freeway. Assign the balance to the alternate route. When determining d_a and t_a , do not overlook the fact that when the freeway obliterates part of the existing road net, d_a and t_a may include some freeway travel. In this case, the "non-users" will be users of the freeway for the portions of the trip where no alternate route is available.

This chart may be expressed: $p = 50 + \frac{50(d + \frac{1}{2}t)}{\sqrt{(d - \frac{1}{2}t)^2 + 4.5}}$ where $0 = p = 100$

satellite and passes through these gravitational limits, we would expect 0 percent attraction at 1.6 and the attraction increasing as it approaches time ratio 0.4. At all points along the path between limits of 1.6 and 0.4 the attraction of the identical stars will be equal when their time ratios are equal and will reach the maximum value at 50 percent when each time ratio equals 0.4.

It would seem that the curves should be symmetrical about 1.0 in the form that when Expressway One has a ratio of 0.6 and Ex-

pressway Two a ratio of 1.6 the percent of usage on the respective expressways should be the reverse of that when Expressway One has a ratio of 1.6 and Expressway Two has a ratio of 0.6. When the time ratio of each expressway is 1.0 the usage of each express-

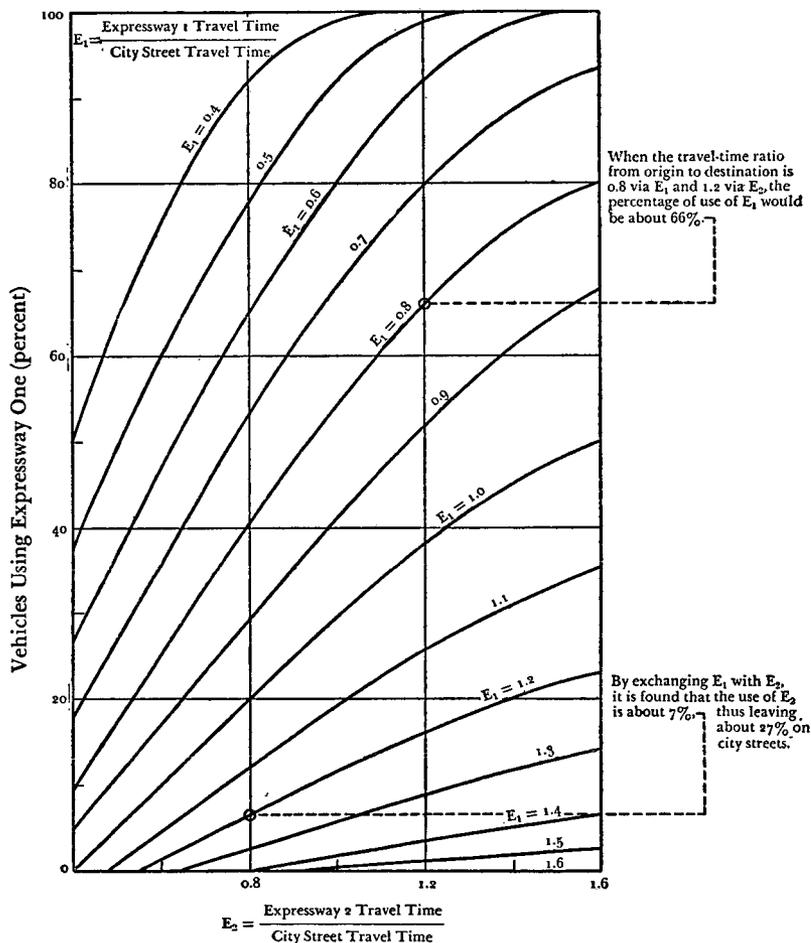


FIGURE IV-7. Usage of two competing expressways (hypothetical).

way should be equal and of the magnitude of 33 percent if the three facilities are equally attractive (when only one expressway is in competition with a city street the two facilities are about equal in attraction when the time ratio is 1.0). If, on the other hand, the opportunity to use either one of two expressways rather

than one only does not make their usage more attractive, then the usage would be about twenty-five percent.

Until empirical data are obtained, one of the following methods may be employed to estimate the usage of competing expressways. In the first method establish a dividing line (an *all or none* line) between the competing routes—the position dependent upon the relative attractiveness of the competing routes.

If two comparable expressways compete, the line may be established midway between them. The relative position of interchanges may affect the placement of the dividing line. If an expressway competes with a boulevard, the dividing line might be drawn to give a twenty-five percent advantage (say 55–45 ratio) to the expressway, keeping in mind, however, that more frequent access points on the boulevard may so reduce the over-all time-saving potential via the expressway that its advantage ratio is narrowed.

The analyst will also consider the zone and street layout between expressways in establishing the dividing line. When the dividing line is established, the trips having origin and destination within the area thus established together with those trips whose centroids fall within this area will be used in estimating the potential traffic on the proposed arterial through this area. Usage is determined by diversion curves.

In the second method, use is made of the diversion curves in Figure IV–2 to determine the amount of traffic that would use the expressway that attracts the most traffic. Now, assume that a lesser attractive expressway is competing for the traffic removed from the streets and may in combination with the other expressway attract up to ten percent more traffic than the single expressway.

Next, add the new increment to that increment already determined to obtain the total percentage of traffic diverted. Then prorate the diverted traffic between the two arteries in accordance with their relative attractiveness (percent of usage as related to travel time ratio.)

In the third method, the diversion curve of Figure IV–2 is used and the second competing expressway is considered simply as the next best alternate through-city street.

It is possible to obtain considerable differences in results

among the three methods outlined. The analyst must decide what method or modification to use on basis of practicability and reasonableness.

Considerations in Use of Diversion Curves: Considerable judgment must accompany the use of diversion curves for there are still a number of modifying factors to be considered. First, the routes being appraised should be comparable to those from which the diversion curves were derived both in transmission qualities and operational characteristics, and particularly in the relation of trip length and position to facility length and position.

While an increase in length of a facility will increase its area of influence in direct proportion, yet frequency of trips decrease as trip lengths increase so that a length of facility may be reached which will contribute relatively few through-trips.

This characteristic suggests the importance of having origin and destination and travel time information as a basis for diversion.

Results of studies made by the Bureau of Public Roads to determine the effect of trip length on the usage of the Shirley Highway extending from Washington, D. C. towards Richmond are shown in Figure IV-8. Interpreting the curves we find that there is greater usage of the freeway by the longer trips when the travel-time ratio is less than 1.0 in correspondence to a greater time-saving possibility. When the travel-time ratio is greater than 1.0 there is less usage by the longer trips in correspondence to a greater time loss possibility. The shortest trip included is 1.7 miles while the longest is 17.1 miles.

Induced Traffic: It is commonly accepted that each new facility or each improved facility may cause this component to be created in addition to causing diversion. This added traffic is observed with the opening of new facilities and has continued as a stable and slightly increasing component for at least the first four or five years as revealed by records covering this period.⁸ In time it becomes increasingly difficult to isolate and measure this component, and it possibly diminishes as the other components grow

⁸ "Influence of Expressways in Diverting Traffic from Alternate Routes and in Generating New Traffic," Roy E. Jorgensen. Proceedings, Highway Research Board, 1947.

and crowd it out. Shifts between modes may add to the component measured as induced traffic. Insofar as it does, there is no increase in total trips through the corridor.

Although a common phenomenon, and often of substantial proportions, little quantitative data are available regarding the amount of traffic induced as a result of adding improved facilities in an urban area.

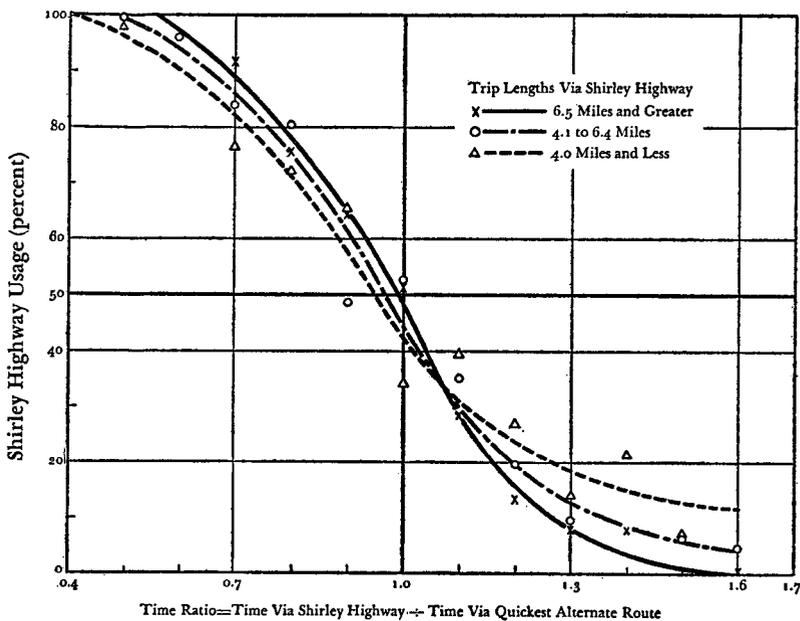


FIGURE IV-8. Effect of trip length on Freeway usage.

SOURCE: Bureau of Public Roads.

Traffic is created by the new facility itself. On the opening of a new road or bridge, a substantial number of trips will be created as the result of curiosity and until curiosity has been largely satisfied, the traffic thus created will remain a substantial part of the use. It is not uncommon for this increment to hold for six weeks or longer before dropping to the normal amount which exists on all ordinary facilities.

In addition to those who make trips to satisfy curiosity, some trips may be repeated to the facility as a point of interest and,

therefore, as a point of destination. No figures are available for facility-created trips as they are usually included with induced traffic trips in the count of new traffic. It has been assumed that the normal facility created component is less than 5 percent of the total traffic using the facility.

Induced traffic is composed of trips previously inhibited by inadequacies in transmission qualities and operational characteristics of existing facilities. With additional capacity and improved operations, the dwelling units increase their output of traffic. This increased output may be an increase in trips generated by the same destinations (e.g. more trips to the CBD) or in trips generated by new destinations. (e.g. change from suburban shopping centers to CBD). It may increase for several years, as may also diverted traffic.⁹

Since induced traffic is composed of trips previously inhibited by inadequacies of existing streets, it appears that the amount of such traffic will be determined by the magnitude of those inadequacies, the increase of adequacy afforded by the new facility (and the schedule of tolls, if toll facility).

Congestion which tends to inhibit travel is a subjective determination and is relative to time, place and person. It depends upon the nature and urgency of the trip and upon subjective responses to the intensity and duration of traffic congestion and attending problems. The same sensitivity to congestion that promotes diversion to freeways even though the travel time is greater will also promote more frequent trips via freeways to the traffic generators.¹⁰

Relation of Induced and Diverted Traffic: While some new facilities have caused little or no increase in total trips, others have induced a new volume to match the diversion. Although quantitative data are not available, enough is known of cases of this nature to provide clear indications that change in magnitude and duration of congestion by the addition of new facilities pro-

⁹ "The Need for Further Research on Traffic Assignment," Curtis J. Hooper. Bulletin 61, Highway Research Board, 1952.

¹⁰ "It is quite apparent that the greatest growth is occurring at the northern end of the (New Jersey) Turnpike, some 26% over last year's figures (1952), as compared to 7% at the southern end. This unbalanced growth is in proportion to the congestion on adjacent roadways." Edmund R. Ricker, *Traffic Characteristics of Toll Highways*, 1953 Proceedings, Institute of Traffic Engineers.

vides an index for the magnitude of induced traffic. It is also believed that the amount of such traffic may be related to the travel-time ratio.

It may be postulated that where maximum diversion occurs, maximum induced traffic is likely to occur if there is adequate capacity; where mean diversion occurs the average induced traffic will occur, and where no diversion occurs the minimum of induced traffic will occur. Except that when there has been no facility previously there can be no diversion and all traffic will be induced traffic. So long as the postulate deals with inhibited traffic, that is, repressed rather than suppressed, it may hold without exception.

The magnitude of induced traffic will depend upon the magnitude and duration of congestion on existing facilities.

Based on this postulate, the relation between diverted and induced traffic may be illustrated graphically as in Figure IV-9.

Congestion Index as Determinant: At this time there is no exact method of calculating the amount of traffic that will be induced by a new facility. The correlation of a before-and-after

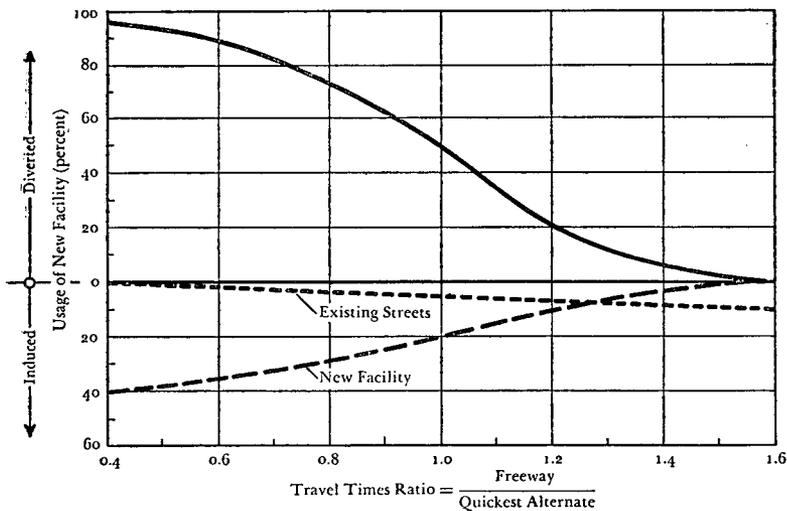


FIGURE IV-9. Postulated relation between diverted and induced traffic.

NOTE: Curves are not intended to portray precise values. A family of curves may be required to peg curve by environment. The relations shown on the diagram apply to zone transfers in the area of influence. If desired, a straight percentage can be applied against diversion.

index value of traffic congestion with the amount of induced traffic would provide useful information. A traffic congestion index should measure both the congestion of the arteries and the terminals, individually, as magnitude of induced traffic is proportioned to the increase of freedom from congestion provided in each of these integral parts of the transportation system.

Several researches now in progress for the purpose of developing an index of congestion are searching for a simple and practicable method of measuring the character of the traffic stream. Among the several concepts for the content of a traffic congestion index are:

1. Density-speed pattern (or spacing-speed pattern)
2. Speed-delay pattern
3. Volume-capacity pattern

Estimation by Analogy: Until a congestion index is developed and correlated with the amount of traffic created by additions and improvements in the highway system, the more feasible method of estimating induced traffic will be to take data from a comparable operating facility in a similar environment. In other words, select known experiences from situations most closely resembling the subject situation. Include among the comparisons as many as possible of the following:

1. Population density and street capacity.
2. Transmission quality of existing streets.
3. Operational characteristics of existing streets.
4. Volume-capacity relations on existing streets.
5. Legal restrictions on speed, size and weight.

The tables below show the volume trends in diverted and induced traffic on some free facilities.

*Southern End of Shirley Highway
Near Junction with US 1*

(In terms of normal growth across the corridor screen line)

	(1950) 1st Year	(1951) 2nd Year	(1952) 3rd Year	(1953) 4th Year
Diverted	47%	38%	54%	60%
Induced	7%	24%	26%	25%

NOTE: Trucks were permitted to use the Shirley Highway beginning May 29, 1951.

Gulf Freeway between Houston and Galveston

(In terms of normal growth across the corridor screen line)

	<i>1st Year</i> (opened in Aug. 1952)
Diverted	50% of corridor traffic
Induced	36% " " "

NOTE: Texas uses fifteen percent to twenty-five percent a year for five years in estimating induced traffic.

Converted Traffic: Converted traffic is that component of traffic resulting from a change in mode. It may appear as a shift between passenger automobile and mass transportation, or shifts between truck and rail transportation. Changes in highway or transportation facilities, changes in fare or tariff, strikes in public transportation, changes in governmental regulations, changes in weather, and other causes are responsible for conversion of mode.

Proportions of usage by various modes of transportation depend upon relative journey time, convenience, and economy, which in turn depend upon dynamics of transportation technologies, management, governmental regulation, capital, operating and maintenance costs.

A change in any of these factors may upset the equilibrium of the several systems, and a shift of mode is required to restore the equilibrium of the interacting forces. For example, a change in speed, fare, schedule, location or length of route, type of bus and other convenience factors are reflected in the patronage of mass transit.

Bus lines are oriented to the central business district to a large degree, and radiate therefrom. The bus lines form corridors of service to patrons. As population density thins toward suburban limits, bus service tends to become unprofitable, service is reduced and eventually withdrawn. In reduced service areas and beyond the end of the line the private automobile finds wider use than in areas nearer the central business district.

Hence, we find an almost uniformly decreasing use of mass

transit and increasing use of private automobiles as we approach the rural areas. Then as urbanization expands outwardly and mass transit lines are extended there is a degree of mode conversion.

Many conversions are local in character, affecting one route or corridor. The estimate of conversion for any particular route should be based on information obtained from the local mass transit company.

An area-wide change in fare will result in area-wide conversion, though not in the same degree in every part of the area. A rule of thumb formula that has been used to predict the amount of conversion is that for a one percent increase in fare there is from one-third to one-half of one percent reduction in patronage. Not all of the reduction becomes conversion.

As to the effect of conversion on traffic volumes, assume that for every 100 present patrons there is an increase of eight and one-half patrons changing from auto to bus. Ultimately we may expect an increase of bus service by this amount. If the average bus should continue to carry about twenty persons, then for each twelve buses one additional bus would be added. With respect to automobiles, for each 100 automobile trips there would be five less since the average occupancy is 1.7.

Assume further that forty percent of the travel is by bus and sixty percent by automobile. Since each bus is assumed to carry twenty passengers it would require two buses for each 100 total trips by both modes and 35.3 autos, or 37.3 of mixed vehicles. It is usual to have one truck for every four automobiles. Therefore when trucks are added the total becomes approximately forty-six. Expanding to 100 and factoring each class of vehicle to its proportionate part of 100 it is found that there are approximately:

Trucks	—	20
Buses	—	4
Autos	—	76

The buses would be expanded by eight and one-half percent or an increase of 0.34 percent in total traffic and the autos decreased by five percent, or 3.8 percent in total traffic. As the shift between

mass transit and auto is not uniform in each area the change in traffic volume will not be uniformly distributed over each route.

III. Traffic Estimates for Toll Facilities

As much attention probably has been given to methods of estimating the traffic potential of toll roads as of free roads. With less than half of an immediate possible 10,000-mile toll road system having been strictly appraised for economic feasibility, there may likely be considerable activity in this field of estimating for several years.

Methods of estimating traffic potential for toll roads parallel those for free roads. Many analysts first estimate the amount of traffic that would accrue to the facility if it were a free facility and then, in consideration of the restraint of tolls, reduce the estimate according to experience in analogous circumstances. The tools of the analyst are, again, the origin and destination study, the time and delay study, plus the toll schedule.

Historical Review of Procedures: It is of interest in tracing the history of toll-estimating to note the method reported in 1940 by Nathan Cherniack of the New York Port Authority and included in the ASCE Transactions for 1941.¹¹ Cherniack's report states, "by determining the 'relative merit rating' of the proposed crossing (either by judgment or by the use of equations six and seven in the Appendix)¹² it is possible to estimate its probable share of any given 'line of travel' (zone interchange) by computing the ratio of its relative merit rating to the sum of the ratings of all its competitors (see Equation five in the Appendix)."

Cherniack continues: "It will be seen that any crossing's share thus depends upon the following factors—(a) the quality of the crossing itself, as reflected in its merit rating, (b) the number of its competitors, as reflected by the number of ratings by which its rating is divided to obtain its share, and (c) the respective qualities of its competitors as reflected in the numerical values of their ratings . . . the share of traffic is determined at different times by:

¹¹ "Measuring the Potential Traffic of a Proposed Vehicular Crossing."

¹² Refers to Appendix in Cherniack report. Ed.

(d) changes in its own or its competitors' relative travel characteristics, such as toll, travel time, distance, and convenience differentials, from those of a standard crossing; (e) changes in motorists' evaluation of those travel characteristics; and (f) a widening of the choice of routes."

In the preamble of his Appendix, Cherniack states, "The formulas are such as to allow for the insertion of judgment factors." The report provides an excellent treatise on the problem and a method of solution.

At about the same time (1939) the Bureau of Public Roads reported their findings with respect to the feasibility of a system of transcontinental toll roads in "Toll Roads and Free Roads."¹³ At that time it was estimated that 172 miles of toll roads would be economically feasible by 1960, and another 666 miles would approach economic feasibility by 1960. Actually, in March, 1955, there were about 2860 miles of toll roads in operation and under construction. This illustrates how difficult it has been, and is, to forecast traffic potentials.

An examination of the method used by the Bureau discloses some concepts still worthy of consideration in an appraisal of toll road potential. The following excerpts from the report indicate the method followed in determining economic feasibility.

As a first step in estimating probable traffic, the selected highways were assumed to be free highways of limited access, but with access points located as they probably would be in a toll system.

The first consequence of the assumed condition was to exclude as potential traffic for the limited-access route that part of the movement on any parallel free highway composed of trips shorter than the distance between assumed access points. In estimating the percentage of the known volumes of traffic on parallel free routes that for this reason would be excluded from the limited access routes, facts concerning the distribution of trip lengths developed by the highway planning surveys . . . proved of helpful guidance.¹⁴ . . .

While the superior design of a new route, if operated as a free facility, would doubtless be considered by potential users as out-weighting some extra distance, there would obviously be no advantage in its use if to reach it at

¹³ Toll Roads and Free Roads, U. S. Govt. Printing Office. Washington, D. C., 1939.

¹⁴ Note that in this 1939 study of economic feasibility origin and destination studies were not available and it was necessary to base the study on traffic flow maps.

one end of a trip and continue from it at the other it were necessary to travel as far over existing cross roads as the distance via a comparable parallel road directly from origin to destination. This consideration would impose a definite limit upon the lateral distance over which the superior facility of the new route would attract traffic from existing parallel roads . . . the number of potential users who . . . would actually choose to use the new facility would increase with reduction in the amount of extra distance involved . . . in relation to the total length of the trip over the new facility. Traffic of long range moving in the general direction of the new facility would obviously be attracted to it from a greater lateral distance than any short-range traffic.

In effect this statement says that as the travel distance or travel time ratio decreases, more traffic will be diverted to the superior facility. The following excerpts from the report provide additional insight into the method used. It is well to remember that the gross national product of 1939 was far less than it is today.

A consideration of the ability of people to pay tolls, as indicated by a distribution of the automobile owners by income groups, and further consideration of . . . fees . . . for specific trips over various sections of the routes, led to the conclusion that not more than about one-third of the vehicles that might use a typical free road of limited access could be regarded as potential traffic for the same road operated as a toll facility. . . .

On the basis of . . . further study, various factors ranging from 0.167 to 0.40 were decided upon for application to the estimated free-facility traffic to convert it to an estimate of traffic on the toll facility.

In densely populated areas, where highway congestion in considerable degree has already been experienced and where there are relatively large numbers of potential users who are able to pay tolls, factors as high as 0.40 were used. This value was used, for example, on Route US 1 between New York City and central Connecticut.

In sparsely populated areas, where thus far little or no congestion has been experienced and existing modern highways afford excellent service, factors in the lower range were used. For example, a factor of 0.20 was used for the section of Route US 30 between Evanston and Rock Springs, Wyoming.

It was further assumed that "travel on the selected routes, operated as toll facilities, would increase approximately one-third faster than travel on all roads." It was also assumed that "generated traffic¹⁵ would appear during the first years of operation of

¹⁵ As used here, "generated traffic" is equivalent to "induced traffic" as used by the authors . . . Ed.

the new facilities, after which time its entire effect upon the rate of increase may be assumed to be eliminated. It is estimated that three years after completion of a route this traffic would increase the total diverted traffic by twenty percent if it were operated as a toll facility.”

Using these relationships, the multiplying factors derived for converting the maximum estimates of 1937 traffic on the selected routes, operated as toll facilities, were 2.5 for 1960 traffic and 34.2 for the traffic of the entire period from 1944 to 1960.

Hindsight, with better perspective, can see that the values used for diversion, induction, and growth were too low.

Another report given in 1939 on the subject of “The Problem of Forecasting Traffic and Revenues” by George W. Burpee, of Coverdale and Colpitts, Consulting Engineers, New York City, is included in “Financing Public Improvements” published by B. J. Van Ingen and Co. Inc. of New York, N. Y. In describing the method Burpee suggests that the patterns of existing traffic first be determined by appropriate traffic censuses, origin and destination surveys and time studies.

After the existing pattern is determined the next question is the amount of probable diversion. “The amount diverted is going to depend upon advantages that the new facility offers . . . in respect to (1) convenience, (2) time saving, (3) distance saving, and (4) the toll which it is proposed to charge.” Each of the advantages is translated into a comparable monetary value and compared with the toll rate to determine the amount of diversion.

With respect to induced traffic, Burpee noted possibilities of an extreme range. “The estimated volume of induced traffic may be tested by comparing the crossings per capita or per registered motor vehicle with crossings in other situations as nearly analogous as may be. The real test is that to determine how many crossings per year the estimate of induced traffic involves in terms of motor vehicle registration generally within a radius of fifteen or twenty-five miles of the bridge.”

Again he states “It isn’t always possible to estimate accurately whether the induced traffic will be thirty percent or fifty percent, but if you estimate conservatively you may be within gunshot if

you take it nearer the thirty percent and you won't be shocked if it goes over fifty percent. But, if you estimated at fifty percent and only thirty percent developed, it would be cause for worry." It should be noted that when Burpee speaks of induced traffic he is relating it to the corridor traffic within the area of influence, and not as a percentage of the diverted traffic.

In the January 1953 issue of *Traffic Quarterly*, published by the Eno Foundation, there was another article by Burpee entitled "Traffic Estimates for Expressways and other Public Toll Revenue Projects." The following excerpts, confirming his earlier method of estimating traffic generation, are taken:

In the case of a toll facility the rates of diversion from existing routes of travel to the new facility are based on user-benefits derived in proportion to tolls paid. The rates of diversion from existing facilities are based generally on distance saved or a combination of both with due consideration to comfort, convenience and safety.

Saving in time, although not directly related to saving in money, appears to be a potent factor in attracting passenger traffic and as a matter of fact, the best index of convenience and ease of use. Saving in distance for trucks can be directly related to costs and is a potent factor in attracting truck traffic. Improved gradients and alignment are also of great importance.

These items measured against the tolls afford a basis for estimating the percentage of potential vehicles that will be attracted to the new facility. In these estimates no high degree of exactness is possible. It is necessary to rely largely on the past history of similar projects. In this process there is no substitute for experience and judgment.

In writing on induced traffic he states "the usual method of estimating is to reason from analogies; that is, to study the history of other facilities . . . similar to the project under consideration."

Another article on "Traffic and Financial Studies for Toll Turnpikes" by William R. McConochie is included in the Proceedings of the Conference on Modern Highways, published by the Massachusetts Institute of Technology, Cambridge, Mass., 1953. The following paragraphs are from the article:

The allocation of potential traffic to a proposed toll road is based on the axiom that time is money. We estimate the timesaving that would accrue to each group of vehicles in going between each pair of origins and destinations.

If the toll charge in a specific instance would be less than the value of time

that would be saved, we allocate an appropriate portion of that traffic to the proposed toll road. The greater the timesaving for any given toll, the larger is the percentage of traffic allocated for that pair of zones. The maximum allocation—usually about eighty-five percent—is made when the value of the time saved would be equal to at least twice the toll charge.

We know, of course, that high toll rates will discourage the use of a toll road. On the other hand, rates that are too low will fail to produce the necessary revenue. It is necessary in each instance to determine an optimum toll charge for each class of vehicle so that maximum revenues will be produced for the project.

If later the traffic volumes exceed the engineers' estimates, the toll rates can be adjusted downward. More use of the facility can thereby be induced without jeopardizing the earnings on which the security of the bond issue rests.

With respect to induced traffic McConochie has this to say: "It is a phenomenon of all transportation improvements that they generate new travel which did not exist before. In the case of bridges replacing ferries, this factor has been known to amount to several hundred percent. It is the engineer's task, and it is not an easy one, to determine how many people who are now staying home because of dissatisfaction with the present highway conditions will be induced to take to the road by the new highway facility."

In connection with the statement by McConochie that the eighty-five percent maximum allocation is made when the value of the time saved would be equal to more than twice the toll charge, it is of interest to compare the statement in the report by Coverdale and Colpitts to the Kansas Turnpike Authority:¹⁶

From an inspection of the data derived from the survey, it was evident that many of the zone-to-zone movements could not use the turnpike advantageously and therefore those movements were excluded as non-potential. . . . The relative times and distances were estimated for each zone-to-zone movement by way of the turnpike and by way of the competitive routes. . . . The relative cost of the use of each route was determined. The out-of-pocket cost of automobile travel was taken at three cents a mile. . . . Wherever the net cost (including the toll charge) divided by the minutes saved was greater than five cents, the movement was excluded as non-potential in computing diversions. The upper limit of cost per minute saved for trucks was taken at six cents.

¹⁶ Report on Estimated Traffic and Revenues of the Kansas Turnpike. August, 1954. Coverdale and Colpitts, Consulting Engineers, 120 Wall Street, New York 5, New York.

A tentative method of estimating traffic on a proposed toll road is as follows:

First, estimate the amount of traffic that would be attracted to the facility if it were a free controlled access highway, using origin and destination surveys together with time-delay studies if possible and using diversion curves to estimate diversion. The percent of traffic diverted would be tempered according to judgment by a knowledge of adequacy and condition of existing roads, and the trip purpose and length and the frequency of trip that would be a potential user of the facility.

Second, from sixty-five to seventy-five percent of this potential free-usage would be allocated as potential toll trips. Empirical data developed in 1954 by the Bureau of Public Roads suggests about forty percent for equal trip time and about ninety percent for equal trip distance, which indicates the range of sixty-five to seventy-five percent for the composite stream.

Third, induced traffic would be added in the amount of about twenty-five percent of the anticipated normal traffic in the immediate traffic corridor.

In estimating the diversion to the proposed Richmond-Petersburg Turnpike, the method used was developed by M. Earl Campbell. It consists of re-calibrating the time-ratio diversion curve to a cost-ratio curve, and using it to determine probable diversions to the toll road from competing free roads in terms of the ratio of cost of travel via toll road to cost of travel via competing free roads.

In translating the time-ratio curve into a cost-ratio curve, certain assumptions must be made with respect to speeds, travel costs and time costs. Since the average ratio of speed of travel via turnpike to speed of travel via alternate free route will not likely be the same for successive pairs of zones of origins and destinations, a family of curves is indicated to take care of the multiplicity of speed ratios growing out of the many probable combinations.

Since the speeds on the approaches to the toll road will determine the over-all average speed of travel via the toll road, it follows that both the numerator and denominator of the ratio will change as successive pairs of origins and destinations are evaluated. A family of curves might begin with a 20:30 ratio and, using

every possible combination of five-mile increments, extend to a 40:60 ratio. This family of curves is necessary, inasmuch as distance as well as elapsed time of travel varies with speed and consequently the cost ratio varies with the speed ratio.

Values used in translating time ratios to cost ratios vary from year to year and from place to place; therefore assumptions of values should be made for each project studied. In order to explain the mechanics of the method, the following assumptions are made:

Average Speed by free road	40 mph
Average Speed by toll road	50 mph
Passenger Car Operating Cost per mile by free road	4.5¢
Passenger Car Operating Cost per mile by toll road	4.5¢
Time cost per minute, either road	2.6¢

(Note: Operating cost on free road at forty mph was set equal to that at fifty mph on toll road due to greater congestion and poorer alinement and grade on free road. Operating costs were used as being more nearly the evaluation of the cost of travel by the driver who is concerned more with out-of-pocket cost than total travel cost. For trucks, assign appropriate values for operating time costs. See page 163 for equivalent values found by consultants in a Virginia study.)

In making the translation, it is necessary to convert the relative time of travel into relative cost of travel. If this relationship is determined for a time ratio of unity it can be applied as a factor to all of the time ratios to translate them into cost ratios. In other words, it can be used to recalibrate the time-ratio curve into a cost-ratio curve. First, determine the cost of travel when the elapsed time of travel is the same by either route. The factor required to reduce the cost via expressway to the cost via the alternate route provides the cost ratio in terms of time. Under these specific assumptions, this factor multiplied by any time ratio translates that time ratio into a cost ratio. For example:

Cost of one minute of travel by expressway at 50 mph:

Time Cost, one minute	2.60¢
Operating Cost 50/60 of one mile @ 4.5¢ per mile	3.75¢
	<hr/>
Total	6.35¢

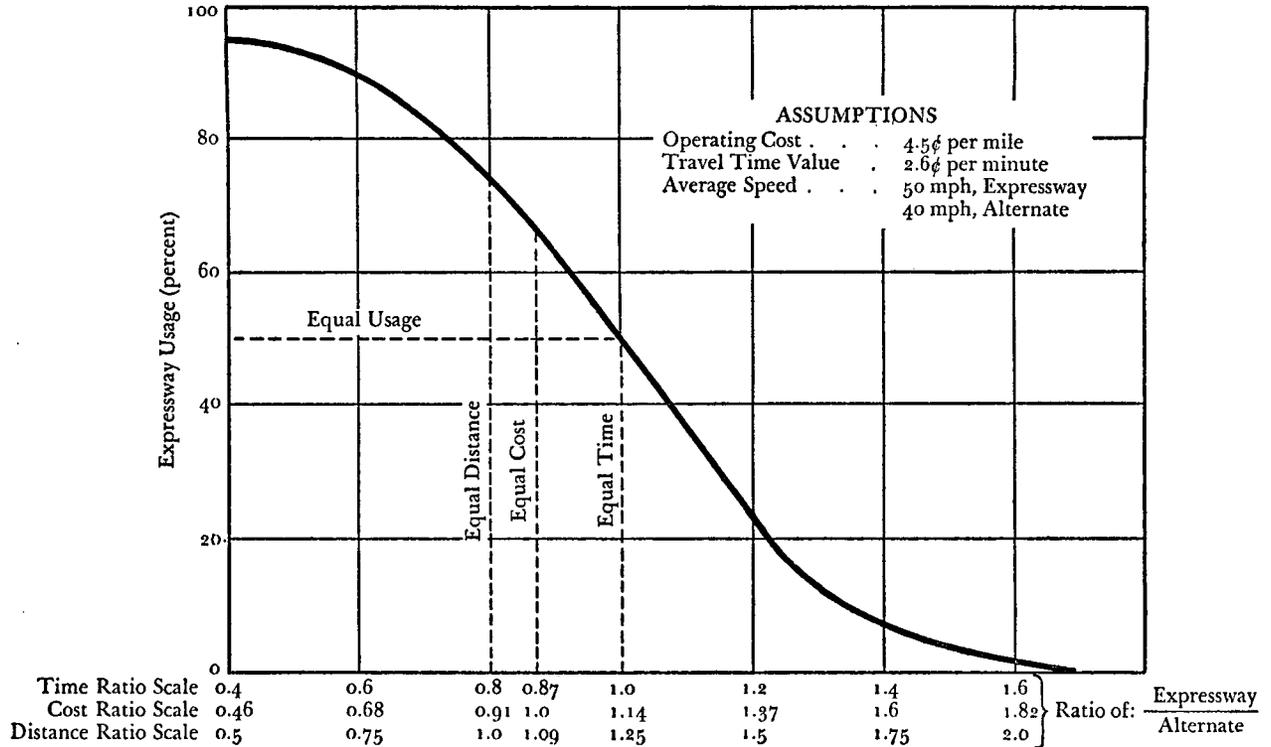


FIGURE IV-10. Diversion curve for free Expressway. Calibrated to show relationship of time, cost, and distance ratios.

Cost of one minute of travel by free road at 40 mph:
 Time cost, one minute
 Operating Cost 40/60 of one mile @ 4.5¢ per mile

2.60¢
 3.00¢

 5.60¢

$$\text{Cost ratio in terms of time} = \frac{6.35}{5.60} = 1.14$$

Hence the related time ratios may be translated into cost ratios by multiplying them by the factor 1.14 (see Fig. IV-10). This relationship holds only for this particular case, where the speed and travel cost relationships are as stated above. The method translates a free road time-ratio diversion curve into a free road cost-ratio diversion curve.

In order to make use of this free road cost-ratio diversion curve in toll road assignment two approaches are possible: the free road diversion curve may be translated into a toll road curve (Fig. IV-11), or the ratio of cost of travel via toll road to free road determined and the diversion ascertained from the free road diver-

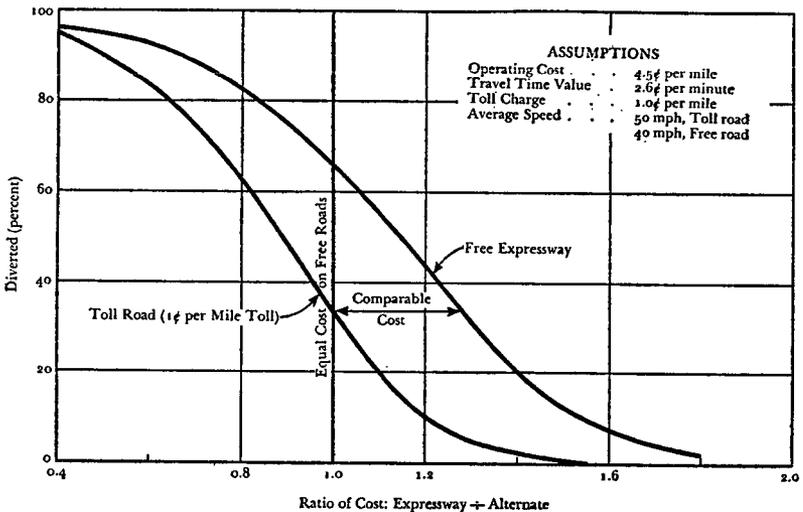


FIGURE IV-11. Hypothetical translation of free road cost-ratio curve into toll road cost-ratio curve.

NOTE: This diagram is illustrative of method and values are not necessarily real. The assumptions will determine location of curve.

sion curve by entering at the point where the cost ratio shown on the curve is equal to the cost ratio determined. For example, suppose a toll charge of one cent per mile is added to the cost of travel via toll road. It is found by calculation that the cost ratio becomes 1.28 when the time ratio is 1.0. The corresponding percentage of diversion to the toll road for a cost ratio of 1.0 is found by entering the free road cost-ratio curve at 1.28 and finding the percent diverted. See Figure IV-11. Likewise the diversion to the toll road for any cost ratio may be found by multiplying the subject value by 1.28 and entering the free road curve at the value of this product.

Under assumptions given in the example, it may be determined that for equal travel distance, diversion from the existing alternate road to the toll road will be about forty-three percent of that on the alternate free route, which compares with about seventy-three percent diversion to a free expressway.

During 1954 consulting firms conducted a study on competing toll ferries and a toll bridge at Newport News, Virginia, for the Virginia State Highway Department. The study was made in order to make an assignment of traffic to the proposed Hampton Roads Bridge and Tunnel System.¹⁷

Equivalent monetary values for time and distance were found and combined with toll charges, and the composite cost related to choice of route in the development of diversion or usage curves. The cost differentials expressed in absolute units provided the best correlation in the usage curves for both passenger cars, Figure IV-12, and commercial vehicles, Figure IV-13.

The curve for automobile trips which agreed most closely with actual habits under present conditions was obtained by computing the motorist's time at two cents per minute and the distance at four cents per mile. Tolls included an extra passenger. The most accurate curve for truck trips was derived when time was computed at five and one-half cents per minute and distance at nine cents per mile. This was for an average truck as found in these studies.

¹⁷ *Allocation of Traffic to the Hampton Roads Bridge and Tunnel System*: Walter A. Barry, Jr. and Marshall Rich. Proceedings, 34th Annual Meeting, Highway Research Board, Washington, D. C. 1955.

In 1954 the Bureau of Public Roads developed additional facts that aid in the estimation of potential toll road traffic. In a circular memorandum to division engineers under date of July 15, 1954, H. S. Fairbank enclosed a manual entitled "Instructions for Preparation of Estimates Needed in Study of Toll Road Feasibility."

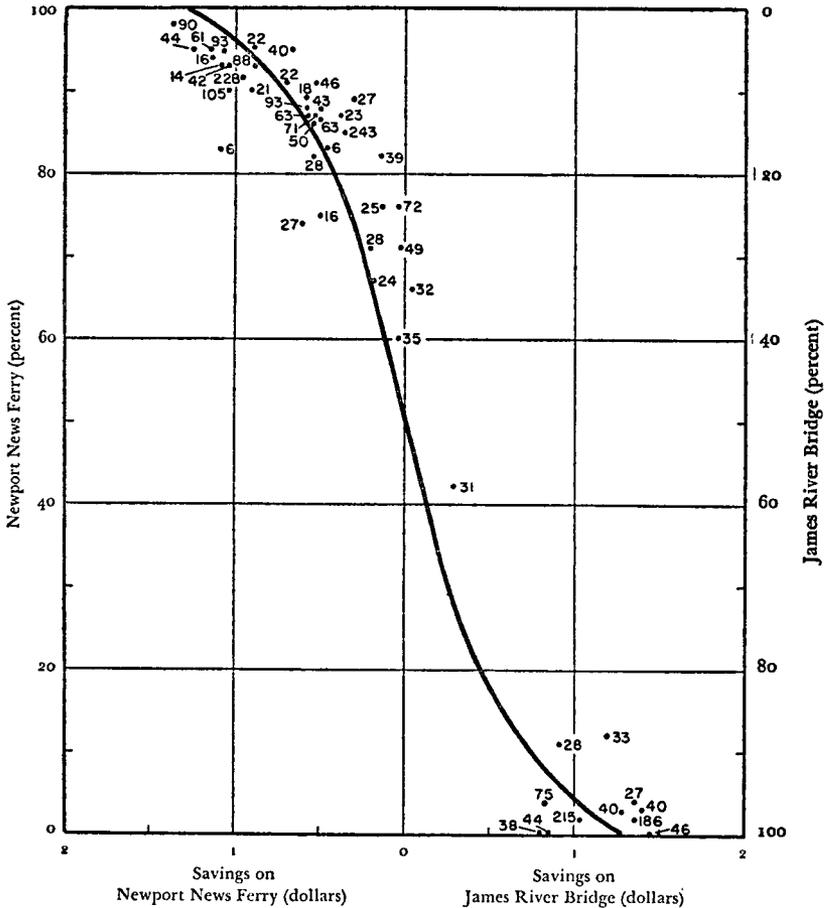


FIGURE IV-12. Newport News Ferry automobile trip costs and usage compared with James River Bridge automobile costs and usage.

Based on time at two cents per minute, distance at four cents per mile, Newport News average automobile toll of \$1.33 and James River Bridge average toll of \$0.80. Light trucks are included as automobiles. Number of trips shown beside points.

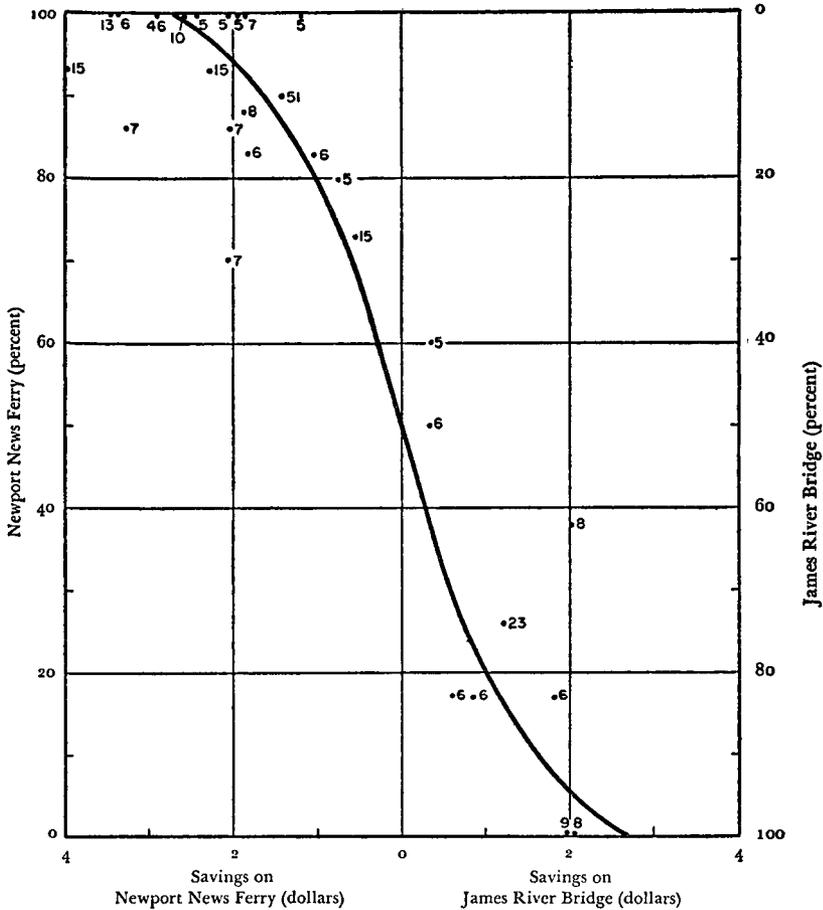


FIGURE IV-13. Newport News Ferry commercial vehicle trip costs and usage compared with James River Bridge commercial vehicle trip costs and usage.

Based on time at five and one half cents per minute, distance at nine cents per mile and average commercial vehicle toll of \$1.93 on the ferry and \$1.77 on the bridge. Number of trips shown beside points.

Tentative curves were provided to show the diversion of passenger cars and trucks to toll facilities.

These curves were developed from a preliminary analysis of the Eastern Extension of the Pennsylvania Turnpike. Since this memo was issued, the study has been completed and reported in *Public Roads* for October, 1955. Revised diversion curves are

shown in Figure IV-14. The diversion of trucks is less than that of passenger cars.

Another observation in the Bureau narrative is significant, namely, "It has been found that an increase in the distance ratio generally results in decreased traffic diversion when the time ratios remain unchanged." At this point it is appropriate to note that the average trip length on the New Jersey Turnpike is about 40 miles, and only 6 per cent of the trips represented full length travel of 118 miles.

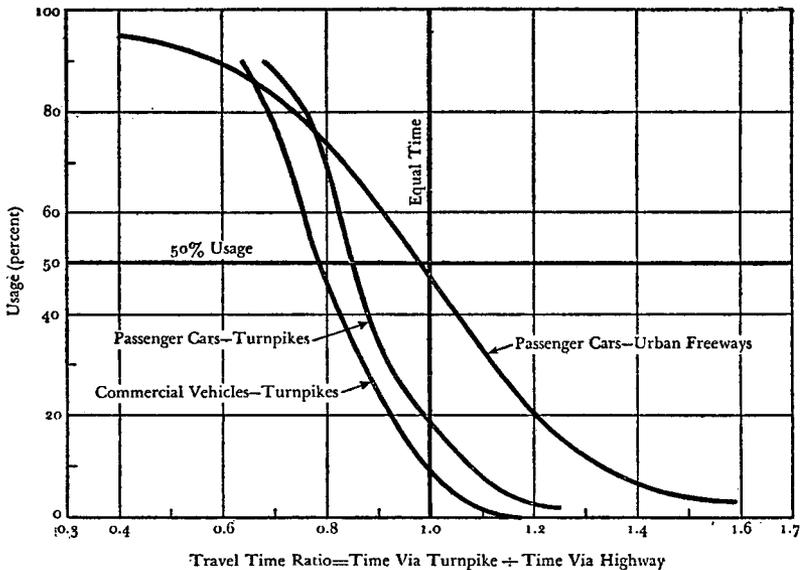


FIGURE IV-14. Traffic diversion curves.

SOURCE: Bureau of Public Roads.

The Bureau manual points out that vacation travel (tourist, recreational) uses the toll roads to a greater extent than other purpose trips, such as social or work trips, particularly on weekends. This statement is given support by a study made on the New Jersey Turnpike in which vacation travel between the North Atlantic States and Florida unbalance the flow on the turnpike as much as 8 or 10 percent during the seasons of travel to and from Florida.

In the absence of origin and destination data and the supplementing time-delay information the Bureau of Public Roads states that "it is estimated that under average conditions, forty percent of the traffic at the low point can be expected to be diverted to the toll facility where there is no great difference in the length of the two routes. This assumes that the parallel highway is the principal road from which traffic is diverted. When there are two or more roads in a corridor, the percentage of the total corridor diversion will be less than when only one highway is involved."

It was noted that the Maine and Denver-Boulder Turnpikes had 40 and 42 percent diversion, respectively, figured at the low point of the road, whereas the Turner Turnpike in Oklahoma had 30 percent diversion, but a high rate of induced traffic. "The 40 percent figure . . . should be varied up or down in accordance with factors affecting diversion."

If a route of considerable length is studied for diversion, for example a length exceeding average trip length by turnpikes, the route should be studied by sections. Section breaks should be determined by conditions in the field, such as distances between major cities to be served, relative density of population along the corridor to be served, and other traffic factors, such as traffic volume changes along the route.

Another section of the same circular memorandum is devoted to "generated traffic." As used in the circular, "generated traffic refers to the amount by which the average daily traffic using a toll road, plus that remaining on the old free highway (or highways) in the corridor of comparison, exceeds the amount that would have been expected on the free highway had the toll road not been constructed."

Table IV-1 summarizes the traffic generation data developed from the several toll roads to which this type of analysis was applied.

The Bureau suggests that a figure of about twenty-five percent be used for traffic "generation," but that it may be advisable to adjust this figure in accordance with the quality of traffic service provided on the existing free highways as related to demand.

Table IV-1
SUMMARY TABLE OF TOLL ROAD TRAFFIC GENERATION

Facility	Date Opened To Traffic	Percentage of Generated Traffic Over Trend by Years				
		First	Second	Third	Fourth	Fifth
Denver-Boulder Turnpike	January, 1952	14	19			
Merritt Parkway	1938 & 1939	28	26	24	25	
Wilbur Cross Parkway	1942	23	20			
Maine Turnpike	December, 1947	11	19	25	28	31
New Jersey Turnpike	January, 1952	14				
Turner Turnpike	May, 1953	44				
Pennsylvania Turnpike (Eastern Extension)	November, 1950	—	23	32		

SOURCE: U. S. Bureau of Public Roads.

Again, it is pointed out that there will be an increment of generated (induced) traffic on the existing free highways pursuant to a substantial diversion to new facilities. With forty percent of traffic diverted from US 1 to the Maine Turnpike it appeared that the induced traffic on US 1, during the first year, amounted to about five percent of the remaining traffic, over and above the increase expected from normal growth.

It is difficult to trace the growth of the several components percentagewise for any lengthy period of time, and particularly so without a succession of origin and destination surveys.

Truck Diversion. Although the ratio of commercial to passenger vehicles on the free roads may be 1 to 4 or 1 to 3, it is found that the same ratio does not usually obtain in the diverted volumes, which may be of the magnitude of 1 to 8 or 1 to 9.

Cost ratios for trucks are usually higher than those for passenger cars. Particularly during the first year of operation, possibly due to existing contracts with drivers, or chartered operations, the trucking companies may not find any greater economy in using toll roads. For example, the ratio of truck mileage in 1954 was 9.9 percent on the New Jersey Turnpike, 8.4 percent on the Turner (Oklahoma) Turnpike, 9.5 percent on the Maine Turnpike, 7.6 percent on the New Hampshire Turnpike, 2.7 percent on the Denver-Boulder Turnpike, and, during 1955, 10 percent on the Ohio Turnpike and 9.5 percent on the New York Thruway.

Annual studies made on the New Jersey Turnpike have showed truck usage increasing from 7.7 percent during 1952 to 9.6 percent in 1953, 9.9 percent in 1954, and to more than 10 percent in 1955.

Uniquely, the average annual ratio of truck mileage to total vehicle mileage during 1954 was about 28 percent on the Pennsylvania Turnpike and about 23 percent on the West Virginia Turnpike, due undoubtedly to the relative cost of operation over the competing facilities. The free roads have heavy grades, sharp curves and numbers of towns and cities, as opposed to easy curves and grades, and freedom from congestion on the turnpikes.

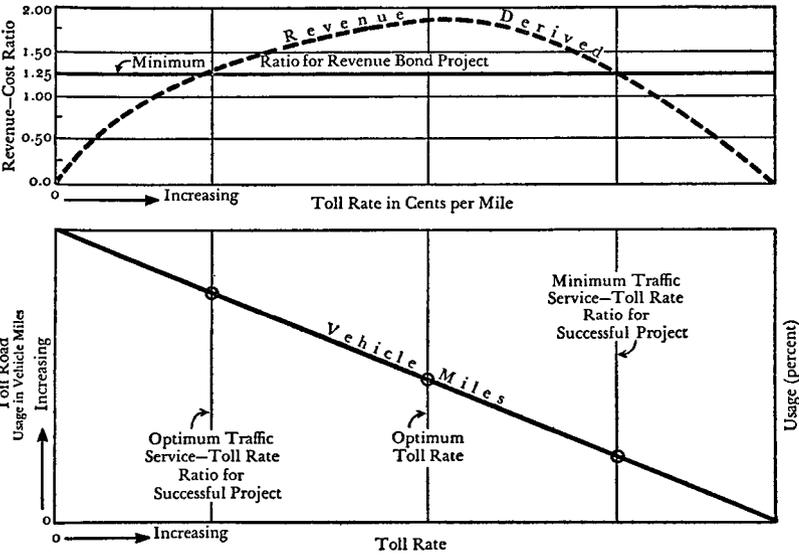


FIGURE IV-15. Illustration of effect of toll rate on usage and revenue.

Optimum Toll Rates. The diversion curve for a free expressway sets the ceiling for toll road diversion. It sets the maxima when toll is zero. The minima is set when tolls outweigh any possible advantage derived from using the toll road. It is reasonable to assume that the imposition of a toll charge will reduce the attractiveness of a route, and that the reduction will be dependent upon the ratio of toll charge per mile to value placed on

travel costs (time and operation cost). Therefore, it is important to try to determine as nearly as possible the values that drivers place upon the several cost elements.

The optimum toll rate may be estimated as follows: Vary the toll structure from a low value to a high value, building from low to high by equal increments. With each change in toll rate, estimate the diversion by referring to the toll diversion curve.

Convert the diversion into revenue, and plot the estimated revenue against toll rate (Fig. IV-15). It will be likely that the revenue line will rise and fall, twice crossing the line of "Minimum Ratio for Revenue Bond Project," once where a maximum of traffic is served and again where a minimum of traffic is served. Between these two points the revenue line will reach its peak, the point of optimum toll rate.

Summary

The methods of estimating the potential traffic volume of a new route have been traced historically from 1940 to date. This was done not only to show the developing state of estimation not yet completed, but also to borrow from the various methods some of the philosophies and principles which are valuable for background and reference.

A higher validity of results should be expected from the empirical methods derived more recently. The greatest advance in this field has been made since 1950. The several diversion curves that have been developed offer a choice for a variety of environments and situations.

Additional data on diversion, induction, and growth are available in Appendix A. They may prove useful as a guide where analogies are found.

SELECTED REFERENCES FOR SUPPLEMENTAL READING

1. Cherniack, Nathan. *Measuring the Potential Traffic of a Proposed Vehicular Crossing*. Transactions, American Society of Civil Engineers, New York City. Vol. 106, 1941.
2. Jorgensen, Roy. *Origins and Destinations of Highway Traffic. The Basis for Connecticut Planning*. Proceedings, Highway Research Board, Washington, D.C. 1943.
3. *Toll Roads and Free Roads*. U.S. Government Printing Office, Washington, D.C. 1939.
4. *Interregional Highways*. U.S. Government Printing Office, Washington, D.C. 1944.
5. Campbell, M. Earl. *Toll Bridge Influence on Highway Traffic Operations*. Eno Foundation, Saugatuck, Connecticut. 1947.
6. *Financing Public Improvements*, B. J. Van Ingen and Co. Inc. New York, N.Y. 1939.
7. Proceedings of the Conference on Modern Highways. Massachusetts Institute of Technology, Cambridge, Mass. 1953.
8. *The Kansas Turnpike. Record of Preliminary Engineering Report*, Produced by the Planning Department of the State Highway Commission. Topeka, March 15, 1954.
9. Burpee, George W. *Traffic Estimates for Expressways and Other Public Toll Revenue Projects*. Traffic Quarterly, January 1953. Eno Foundation, Saugatuck, Connecticut.
10. Gruen, Victor. *Traffic Impact of the Regional Shopping Center*. Traffic Engineering, Vol. 23, No. 6, March 1953.
11. Glaze, C. K. *This Business of Highways*. Traffic Quarterly, January 1953. Eno Foundation. See also Traffic Engineering, December 1952.
12. Mylroie, Willa W. *Predicting Intercity Traffic*. Northwestern Conference on Road Building, Proceedings. University of Washington, 1952.
13. Pratt, Charles O. *Department Stores and Parking*. Traffic Quarterly, January 1952. Eno Foundation, Saugatuck, Connecticut.
14. ITTE. *Reference Material on Estimating Potential Traffic on Proposed Urban Highways*. ITTE, Information Circular No. 25, 1952.
15. Jorgensen, Roy E. *Influence of Expressways in Diverting Traffic from Alternate Routes and in Generating New Traffic*. Highway Research Board Proceedings. Vol. 27, pp. 322-330, 1947.
16. *Traffic Assignment*. Bulletin No. 61, Highway Research Board, Washington, D.C. 1952.
17. Thompson, J. T. and Stegmaier, J. T. *Effect of Building Space Usage on Traffic Generation and Parking Demand*. Highway Research Board Proceedings Vol. 28, pp. 320-339, 1948.
18. Ricker, Edmund R. *Traffic Characteristics of Toll Highways*. Proceedings, Institute of Traffic Engineers. 1953.

19. *Federal Aid Highway Act Toll Road Feasibility Study*. Circular Memorandum to Division Engineers from H. S. Fairbank, Deputy Commissioner Bureau of Public Roads, Washington 25, D.C. July 15, 1954.
20. *The Garden State Parkway-Traffic and Toll Revenue Estimates* by Samuel P. Brown, partner, Coverdale and Colpitts, consulting engineers, New York. ASCE Convention, June 17, 1954.
21. Kennedy, W. Norman. *Some Considerations in Toll Road Analysis*. Proceedings, Sixth Northwest Conference on Traffic Engineering, University of Washington, Seattle. 1953.
22. Kennedy, W. Norman. *Some Aspects of the Rapid Transit Situation*. Institute of Transportation and Traffic Engineering, University of California, Berkeley, California. Technical Memorandum B-19. (Intra-departmental) 1953.
23. Rothrock, C. A. *Urban Congestion Index Principles*. Bulletin 86. Highway Research Board, Washington, D.C. 1954.
24. *Diversion of Traffic from City Streets to Expressways*. Circular 139. Highway Research Board, Washington, D.C. 1951.
25. Campbell, M. Earl. *Route Selection and Traffic Assignment*. A Compendium of Correspondence. Highway Research Board. Mimeo. 1950.
26. Brown, R. M. *Expressway Route Selection and Vehicular Usage*. Bulletin 16. Highway Research Board, Washington, D.C. 1948.
27. *Status of Toll Road Projects in the United States*. American Highways, October 1954. American Association of State Highway Officials, National Press Building, Washington, D.C.
28. Campbell, E. Wilson and McCargar, Robert S. *Objective and Subjective Correlates of Expressway Use*. Detroit Metropolitan Area Traffic Study. Bulletin 119. Highway Research Board, Washington, D.C. 1955.
29. Lynch, John T. *Traffic Diversion to Toll Roads*. Bureau of Public Roads. A paper presented at the Annual Meeting, American Society of Civil Engineers, New York City. 1954.
30. Conner, Melvin A. and Hiller, Sherwood H. *Surveys in Miami Show Stability of Origin-Destination Patterns*. Traffic Quarterly, October 1954. Eno Foundation, Saugatuck, Connecticut.
31. Row, Arthur T. *An Approach to O-D Data Analysis*. Detroit Metropolitan Area Traffic Study. Traffic Quarterly, January 1955. Eno Foundation, Saugatuck, Connecticut.
32. Fielding, Roy H. and Young, Thomas E. *Analysis of Flow on an Urban Thoroughfare Traffic Control Project*. Bulletin 107. Highway Research Board, Washington, D.C. 1955.
33. Bunting, Ernest W. *Induced Traffic on the Chesapeake Bay Bridge*. Bulletin 119. Highway Research Board, Washington, D.C. 1955.
34. Greenshields, Bruce D. *Quality of Traffic Transmission*. Proceedings, Highway Research Board, Washington, D.C. 1955.
35. *Bibliography on Toll-Roads*. Compiled in the Library of the U.S. Bureau of Public Roads, Washington, D.C. July 1954. Mimeo.

36. Mortimer, William J. *Trends in Traffic Diversion on Edens Expressway*. Bulletin 119. Highway Research Board, Washington, D.C. 1955.
37. Olayos, Jr., John M. *Methods Used by the California Division of Highways for Estimating Induced Traffic*. Proceedings, Institute of Traffic Engineers. 1950.
38. *Economic Feasibility of Delaware Expressway*. Philadelphia City Planning Commission, by Madigan-Hyland, consulting engineers, New York City.
39. *Progress and Feasibility of Toll Roads and Their Relation to the Federal Aid Program*. House Document 139, 84th Congress, 1st Session. U.S. Government Printing Office, Washington, D.C. 1955.
40. *Mechanized Method of Traffic Assignment*. Bulletin 130. Highway Research Board, Washington, D.C. 1956.
41. Carsten, Winsten H. *Directional Contour Maps of Travel Desire*. Bulletin 153. Highway Research Board, Washington, D.C. 1956.
42. Row, Arthur. *Directional Analysis of Vehicle Travel Desire*. Detroit Metropolitan Area Traffic Study. Bulletin 153. Highway Research Board, Washington, D.C. 1956.
43. Rothrock, Claude A. and Keefer, Louis E. *Measurement of Urban Traffic Congestion*. Bulletin 156. Highway Research Board, Washington, D.C. 1956.
44. Walker, Willam J. *Report of Committee on Operating Speeds in Urban Areas*. Bulletin 156. Highway Research Board, Washington, D.C. 1956.
45. *Traffic Study*, Parts I and II. Detroit Metropolitan Area Traffic Study, Detroit, Michigan. 1956.

CHAPTER FIVE

TRAFFIC GROWTH

Planning looks toward the future. It thus entails forecasting. Once stigmatized as "an unavoidable responsibility," forecasting has now become an accepted routine planning function. Empiricism and informed judgment provide the best basis for forecasting at this time.

As time passes, the empirical method acquires a longer focal distance and thus obtains a higher degree of precision in the projected trend. In other words, since forecasting is a projection of hindsight into the future, it follows that the better the hindsight, the better the foresight, or forecast.

But in addition to the projection of hindsight, the planner must recognize the shadows of coming events, the developments in science and technologies both directly and indirectly affecting transportation. Many factors of influence have not yet developed to the point where they have become significant parts of historic trends, yet they may play an important part in transportation in the forecast period. Each developing component should be evaluated with the best-informed judgment with respect to its growth, its cause, its place as supplement or substitute.

From travel forecasts are determined the physical needs and consequent fiscal needs. On the one hand there is a determination of need, in time and place, for additions, betterments and new facilities, and their design, operation and maintenance—the long-range needs program. On the other hand there is the determination of estimated revenues which provides a basis for long-range fiscal planning. This long-range planning assists in determining justification, priority, scheduling and phasing of improvements, and apportionment of funds.

All factors contributing to the volume of traffic and its distribution by route also affect traffic growth. While the time factor is significant in normal growth there are vital contributing factors which affect both growth and distribution, such as shifts in popu-

lation, industry, and commercial centers, degree of saturation of existing highway facilities, mode competition, and level of economy.

Forecasts of traffic should be conservative, that is, within safe bounds, involving little risk. Since forecasting is not foretelling, conservatism may require two estimates, one of higher traffic volume for design and one of lower traffic volume for probable revenue. In designing for the future, provision for increased capacity may be more cheaply obtained at the time the facility is planned than after the facility is built; therefore the estimate for design should be in accordance with the best judgment of probable growth for the subject facility and should not be ultra-conservative. However, in scheduling amortization it is customary to provide a margin of error for unpredictable events and for elements of uncertainty.

These may include fluctuations in economy; artificial restrictions such as reduction of unnecessary travel in time of national emergency; increased competition from other routes or modes of travel; and other contributing influences. Hence, a low estimate is a safe estimate for fiscal programming, and is of particular necessity for facilities financed by revenue bonds. Another safety factor employed to assure security of revenue bonds is to insist on a coverage (the ratio of estimated net revenue to estimated cost of facility) of 1.25 to 1.50 or better.

Methods of Forecasting: Several procedures have been developed for forecasting, each employed in accordance with attendant requirements. These procedures are sometimes classified as mechanical or analytical. The mechanical method simply projects forward the composite past trend "assuming that future experience is a direct function of past experience."¹

The analytical method classifies and analyzes the several related components or influence factors that have formed the historical trend pattern, taking into consideration developing stimuli which will become influential in the future. The analytical method recognizes that simple extrapolation for a long-time period may lead to absurdities.

¹ *Principles of Engineering Economy*, Eugene L. Grant. The Ronald Press Co. New York, 1930.

These two procedural types of forecasting include the following methods:

Mechanical

- a. Correlation index
- b. Ratio
- c. Analogy
- d. Projection of Composite Trends
- e. Growth Formulas

Analytical

- a. Projection of Component Trends
- b. Expansion of Existing Patterns
- c. Synthesis of Hypothetical Patterns

Each of the above methods will be discussed.

I. Mechanical Methods

1. *Correlation Index*: In estimating vehicle miles of travel area-wise, attempts have been made to relate travel to trends in growth of other items in order to obtain a relatively simple index for use in traffic estimates. Among the correlations tried, those of gasoline consumption, the national income (1935-39 dollar base) and the gross national product provide good correlation. With the gross national product expressed in 1939 dollars, and with 1940 as a base year (both for traffic on all U. S. roads and streets and gross national product) it is found that their trend lines, except for war years, are nearly coincident,² and have moved steadily one with another since 1931. See Figure V-1.

Both traffic and the gross national product increased at an average rate of about four percent a year compounded from 1936 to 1951. It was predicted that the gross national product will continue to grow until 1970 at a rate of about four percent a year compounded annually. As of 1955, the figure for total vehicle miles in the United States is equal to about three times the figure for gross national product (1939 dollar).

A correlation of total United States traffic with the national income reveals a close parallelism between them since 1932, as

² *Traffic to Come*, E. H. Holmes, Bureau of Public Roads. Presented at National Safety Congress, 1951.

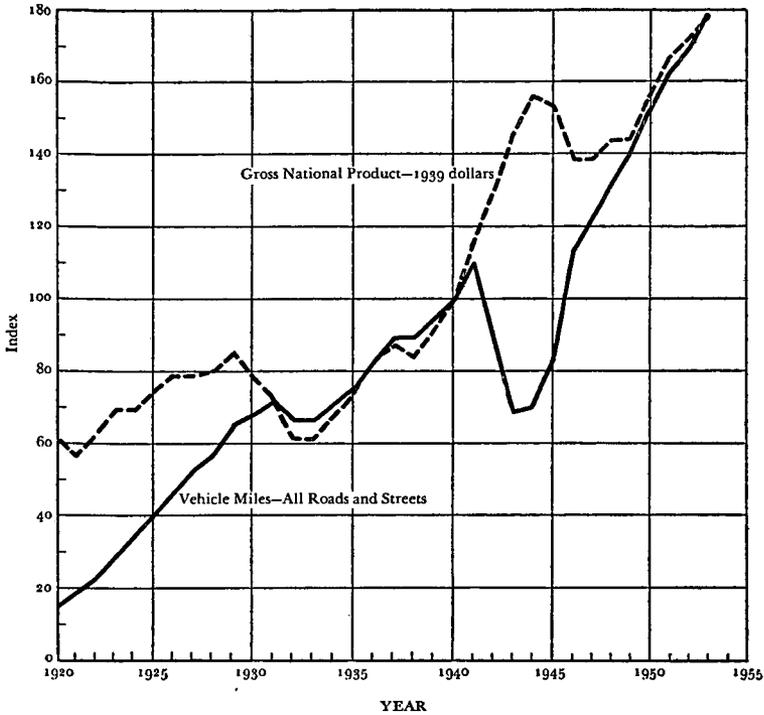


FIGURE V-1. Index of the gross national product and vehicle-miles of motor-vehicle travel. 1940=100.

SOURCE: "Traffic to Come," E. H. Holmes, Bureau of Public Roads.

in Figure V-2. Except for the wartime period, for nearly twenty years the ratio of travel miles to 1935-39 dollars has held between three and one-half and four.³

Correlations with gasoline consumption depend upon the selection of an index figure for miles driven per gallon of gas. See Figure V-3. Gasoline exempted from taxation because used for off-highway purposes should not be included in gas consumption figures, but it is not known how precise the records are on gas tax refunds. If the average car travels thirteen and seven-tenths miles a gallon of gasoline and the average truck travels ten miles a gallon, and if the truck travel constitutes twenty percent of

³ *What's Ahead in Traffic Volumes*, E. H. Holmes, Bureau of Public Roads. Presented at 21st Annual Meeting, Institute of Traffic Engineers, 1950.

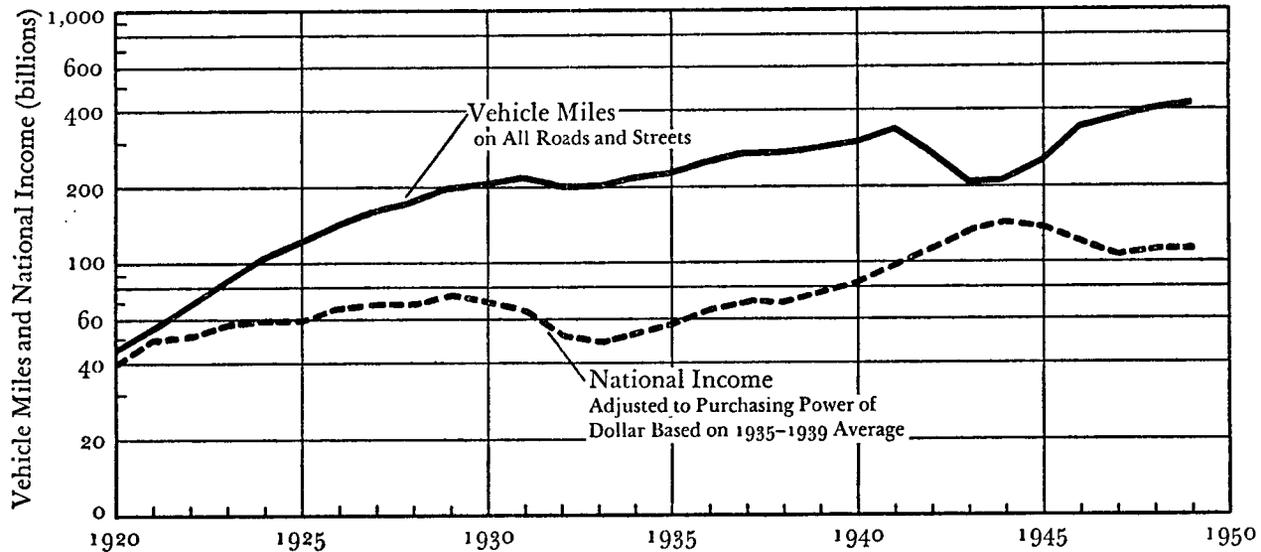


FIGURE V-2. Motor vehicle travel and national income, 1920-1949.

SOURCE: "What's Ahead in Traffic Volume," E. H. Holmes, Bureau of Public Roads.

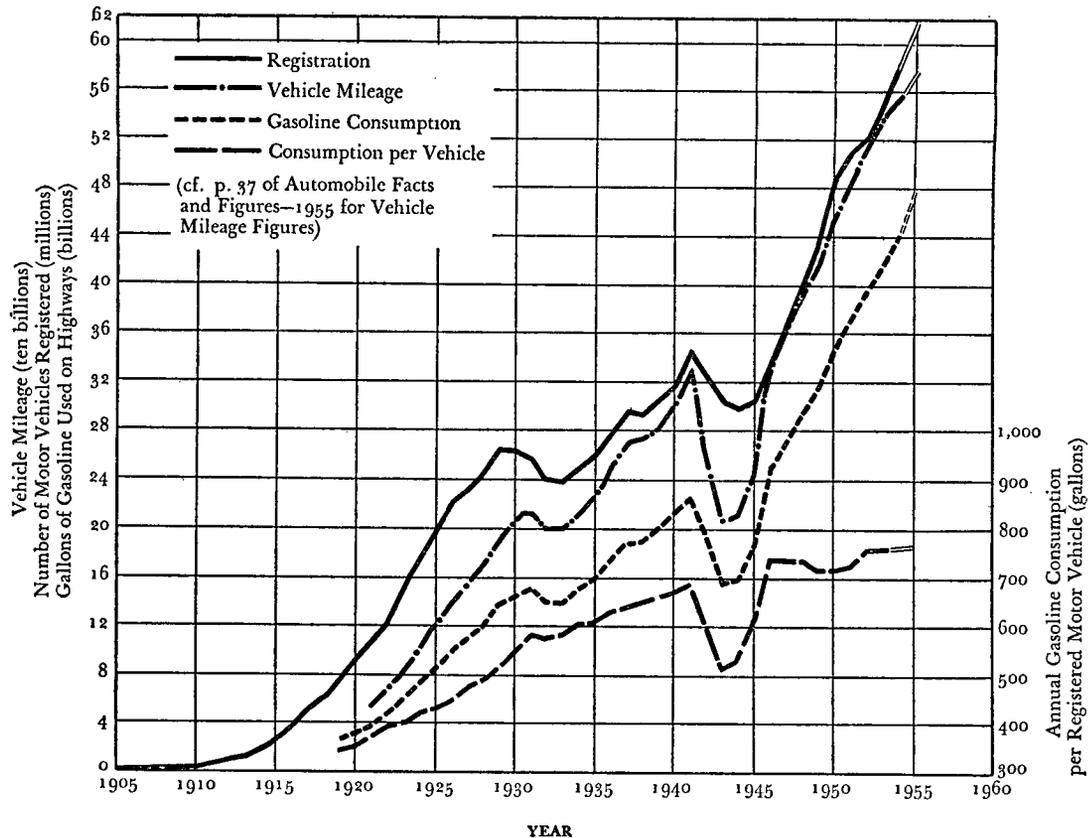


FIGURE V-3. United States trend in motor-vehicle registration, gasoline consumption, and travel, 1905-1955.

SOURCE: "Highway Statistics, 1953, Bureau of Public Roads."

total travel, then the average composite vehicle travels about thirteen miles a gallon. If gasoline consumption figures are to be translated into mileage figures, the figures for mileage per gallon should be used which apply to the subject area.

If the trend of gasoline consumption is used to determine only the rate of growth, the rate may then be applied to the existing vehicle mileage figures. In either case the trend line of gasoline consumption should be correlated with the trend line of vehicle mileage to ascertain their parallelism, for the relative mileages of various weights of commercial and passenger vehicles are changing and the gasoline consumption per mile for new models of vehicles is also changing to some extent.

Correlation analysis may serve very practicably in the portrayal of composite growth of travel in the United States or in each of the several states, inasmuch as data may be obtained relative to income, production and gasoline consumption on a national or state-wide basis. Such data are usually not obtainable, nor are they as applicable, for estimating on a one-project or local basis.

2. *Ratio*: The predicted growth of a component may be related to the predicted growth of the whole (e.g. city to state) by correlating the growth of the component to the growth of the whole. To illustrate, if city growth is to be estimated, its past rate of growth is compared to the past rate of growth of the state and then projected in terms of estimated state growth. Estimates for states are usually more readily available than estimates for cities.

3. *Analogy*: Analogy is defined as "a relation or likeness, between two things or of one thing to or with another, consisting in the resemblance not of the things themselves but of two or more attributes, circumstances or effects." The root word means "according to due ratio, proportionate."⁴

Insofar as antecedent situations may be found which bear resemblance to the subject situation, a prototype of development is provided. Other historical factors must also be taken into account for parallelism: rate of growth, economy, geography and other

⁴ Webster's Collegiate Dictionary.

related circumstances. By analogy the growth expectancy of one city of say 25,000 population may be indicated by comparing it with another city of greater population for both of which the attributes and patterns of development were nearly the same for the years in which they grew to 25,000 population.

Again, by analogy, if a situation may be found which historically parallels the subject situation in several attributes and has adequate records of traffic behavior and growth whereas the subject situation does not have such records, then the trends in behavior and growth of traffic may be appropriated as a pattern for the subject situation and used as a guide in projecting future growth. In other words, if one city has been thoroughly studied for long range development and its future development forecast, then this forecast may serve as a pattern for another city which closely resembles it in size, economic and ecological attributes.

For another example of the use of analogy, if a new superior highway is to be built, some indication of rate of traffic growth on it may be obtained by finding the rate of growth on a highway in an area similar with respect to total thoroughfares, population density and economy.

The area of influence will be the area which finds a new facility more attractive than existing facilities by reason of benefits derived from its use, such as time, distance, or monetary savings; freedom of movement or freedom from delays; or for its intrinsic attractiveness. Although the area of influence is not clear-cut, for purposes of estimating the minimum limits may be expressed as follows:

The limit laterally opposite, and on each side of the facility, is a distance equal to about one half the length of the facility, or in the case of a bridge, a distance equal to at least half the distance to the next bridge or ferry. The width limits actually relate to the distance from the centroid of the trip desire line to the centroid of the subject facility, and thus the limits do not define a geographical area. The limit longitudinally is indeterminate in a sense, for time may be saved from any longitudinal distance in the projection of the axis of the facility, or for *cross-over* trips.

Assuming the attraction decreases with the square of the dis-

tance, the attraction at ten miles is one percent of the attraction at one mile. This hardly seems realistic for a facility which is longer than a bridge. Another device for determining the effective longitudinal distance is to relate the distance to the frequency distribution of travel distance. The average trip length is about fifteen miles, and ninety-five percent of all trips are less than fifty miles in length. On the other hand, all the long trips will likely seek the superior facility. Nevertheless, in order to determine an index of analogy influence areas may be taken as follows:

Total width of influence area = length of facility

Total length of influence area = length of facility plus 25 or 30 miles

As a matter of refinement, and more particularly in the case of bridges, the influence area may be divided into concentric circles or ellipses, and these into sectors. The corresponding sectors in each influence area are given corresponding identifying numbers, and the analogy thus carried through on a sector basis. All other things being equal, the amount of traffic attracted and rate of growth in any given situation would be proportional to that of the analogous situation for which attraction and rate of growth are known.

While analogy provides a pattern and a helpful guide in estimating, it should not be followed blindly. Antecedent situations can hardly coincide exactly with present situations nor can parallel situations coincide exactly with each other. They do provide a guide in a local situation that a correlation with gasoline consumption cannot.

4. *Projection of Composite Trends:* Records of traffic volumes may be plotted and the curve projected forward in a continuation of the apparent trend through the forecast period. The curve may be drawn visually or mathematics may be employed to obtain the best fit. Since forecasting at best reflects informed judgment, a visual fit and extrapolation may be the practical procedure. Allowance should be made for any foreseeable changes in competition created by new facilities, changes in mode of travel, changes

in land use, or approach of the saturation point in land use or capacity of facilities.

It has often been observed that traffic within a corridor may increase at a normal rate each year, until a new facility is built. Then there is an almost immediate increase of from twenty to twenty-five percent in corridor traffic, plus an increased rate of growth. This phenomenon provides a warrant for building a new facility in advance of the date when estimated diversion at the normal rate of growth would provide adequate revenue for its support.

5. *Growth Formulas*.⁵ Formulas have been used to forecast the traffic volume for some future year in accordance with various concepts of growth or observation of historic trends, such as (1) straight line (addition of constant increment each year); (2) compound interest curve, (3) general growth law, and others.

(1) *Straight Line*: If it is assumed that a constant increment will be added each year, which is unlikely but may provide an approximation as close as any prediction for a brief period of time (one or two years), the forecast may be stated in mathematical terms as follows:

$$V_n = V_o + an$$

in which:

$$\begin{aligned} V_n &= \text{Volume at end of forecast period} \\ V_o &= \text{Volume for base year of forecast} \\ a &= \text{annual constant increment of growth} \\ n &= \text{number of years in forecast period} \end{aligned}$$

(2) *Compound Interest Curve*: It appears that the national traffic growth has followed a compound interest curve for about fifteen years and may possibly follow this type of curve for another ten or fifteen years with an increase of 4 percent compounded annually.⁶

The formula for this type of curve is:

$$\begin{aligned} V_n &= V_o (1 + v)^n \\ \text{or } \log V_n &= \log V_o + n \log (1 + v) \end{aligned}$$

⁵ From Cherniack and from Grant. Ibid.

⁶ *Traffic to Come*, E. H. Holmes, 1951.

in which:

V_n , V_0 and n represent the same values noted above and v = annual percentage of traffic increase over preceding year.

(3) **General Growth Law:** A concept of growth commonly used in the biological sciences, and applied also to population and new industries, is used to some extent in traffic. It assumes a slow but constantly accelerating rate in the early years, then a period of rapid and steady growth followed by a decelerating rate until the curve continues on with minimum or no further growth when the saturation point is reached.

Past traffic trends have followed this law rather closely. There was the slow start with the advent of the automobile and the accelerated growth as vehicle production and paved highway mileage increased. The rapid rise of the twenties followed, with less active growth during the depression years of the thirties. Some mistaken analysts thought we were approaching the saturation point.

There followed an upward swing in economy and a parallel rise in travel which upset theory. It is evident that the saturation point is tied to the economy, as well as to expansion of facilities, and it is impossible to predict when, if ever, saturation will be reached. The parameters are unknown.

The Pearl-Reed and Gompertz theories are founded on the general growth concept. The Pearl-Reed "general growth and autocatalytic" formula is:

$$V_n = \frac{V_m}{1 + mR^n}$$

in which:

V_n = volume in any given year

V_m = maximum annual volume as determined by the aggregate capacities of all the facilities

m = ratio of the margin of capacity to the annual volume in the base year

R = annual rate of change in the ratio of margin of capacity

n = number of years between base year and given year

An interesting theory for prediction of population was proposed by Malthus in 1798 and published in his first Essay on the Principles of Population. Malthus pointed out that population if unchecked tends to increase in geometric proportion and has a tendency to double every twenty-five years. It is hardly necessary to state that experience has not altogether substantiated the Malthus theory. Similarly, although the Pearl-Reed growth formula is sound in theory it becomes in its application a "dress for guess."

II. Analytical Methods

When analytical methods are used in traffic forecasting, recognition is given to the fact that traffic growth is a product not only of time but of certain varying internal forces and external stimuli that operate to affect the rate of growth of each contributing factor to the composite growth. These forces are reflected in the growth trends but they should be isolated and studied for their individual as well as combined effect.

They are sometimes referred to as operative factors, since they operate to affect the rate of change in the basic traffic determinants. (Basic determinants will be discussed under "Projection of Component Trends.")

Quantitative values for the operative factors should be determined in the area of the forecast, if possible. Inasmuch as some of the operative factors are intangible, it may be difficult to appraise their effect quantitatively, yet the effect may provide a margin of safety to the estimate, if of an additive character.

Included among operative factors are:

(1) *Level of Economy*: It was found by E. H. Holmes⁷ that total vehicle miles in the United States have been almost directly proportional to the national income in terms of the 1935-39 dollar, and to the gross national product for more than fifteen years. This proportionality will not hold in any local area because of differences in other vital operative factors but if all other conditions were the same, it appears that travel would approach

⁷ op. cit.

parallelism with income, and at median value of three and one-half to four miles per dollar of income (1935-39 dollars).

Studies made by the Bureau of Public Roads to determine travel in relation to income bears out this hypothesis, but due to differences in other operative factors, including social as well as economic differences, the vehicular mileage was not directly parallel to net income. In other words, for the composite American the relation holds, but for the individual or component group it may not.

Changes in cost of living, value of the dollar, and cost of car ownership and operation are accounted for in some measure by using the 1935-39 dollar. Apparently there are some operative factors at the present time, such as more leisure time, better automobiles, and better or more extensive mileage of roads, which have compensated for any reducing factors.

(2) *Extent and State of Improvement of the Highway system or Subject Project:* From 1921, when 387,000 miles of the rural road system in the United States were surfaced, until 1931, when 830,000 miles were surfaced, the vehicle mileage increased from one vehicle-mile per dollar of national income to four vehicle miles per dollar of adjusted national income. Then there was a stabilization at about three and one-half to four miles per 1935-39 dollar.

Such rates of growth are not implicit to system improvement in the future. It did not continue at the same ratio after this ten-year period. This four-fold increase in ten years represents the satisfaction of a demand existing in 1921. This unsatisfied demand resulted from travel desire unmatched by travel facilities—sufficient pavements and motor vehicles.

New turnpikes have served an unsatisfied demand, for they have added an increment to corridor travel of about twenty-five percent above the projected trend. This added increment holds at this figure (or sometimes gradually increases) until the practical capacity of the turnpike is approached.

It is evident that use of new facilities is measured in terms of unsatisfied potential and the limiting factors of time and money.

(3) *Changes in Competition:* Whether represented by change in cost or convenience of competitive modes; change in number, character or tolls of competitive routes of travel; or change in competition among market places—these changes are reflected in travel both in total amount and in distribution. Technological developments, government regulations, additions and betterments to the highway system, establishment of suburban shopping centers—these and other changes—cause changes in travel magnitude (growth) and direction (distribution). Competition by mode, route, or generator may divert, and may also change rate of growth of residual traffic volume.

The character of the residual must also be evaluated in terms of the several operative factors for a determination of growth. Quantitative data are lacking on effect of competition on growth, and but little are available on its effect on diversion. A rule of thumb for effect of fare change in mass transit is that for each one percent increase in fare there is from one-third to one-half of one percent loss in patronage. But this relates to diversion and not growth. As a matter of fact, mass transit, nationwide, is declining in patronage at a present rate of about ten percent per year. Undoubtedly much of this reduction is conversion to auto travel.

(4) *Purpose of Travel:* Rates of growth are related to purpose of travel. Work and business trips grow with employment and may be related to national income in the same ratio as employment is related. On the other hand, recreational or pleasure travel is related to amount of leisure time and cost. Recreational travel also shows greater seasonal fluctuation. Extension of travel facilities and promotion of travel are also reflected in its growth.

It is obvious that the sizes of visiting and visited populations affect volume of social visits; size of the working population (or business population) and type and magnitude of industry affect volume of work or business trips; size of population and character of recreational area affect volume of pleasure trips; and size of population and types and sizes of shops affect volume of shopping trips. In all of these relations, distance also has an effect.

But the attraction may be people, industry, place, or shop, ac-

ording to purpose of trip, and therefore a specific formula of the type $V = \frac{P_1 P_2}{D^x}$, which does not contain all the purpose components, cannot be applied indiscriminately to different areas unless there be analogous components of trip purpose.

(5) *Change in Land Use*: Growth and shifts in population, industry, commerce, recreational facilities and other traffic generators will show a corresponding change in traffic volume, but not always in direct proportion. As a city grows in population, travel to the central business district does not increase at the same rate. It has been found that with respect to shopping trips, a city approaches the saturation point at about 250,000 population with about 6,000 shopping trips a day to the CBD.⁸

As the suburbs expand outwardly beyond mass transit routes, it is found that trips by auto increase markedly—as much as twice the number made in areas served by transit.⁹ The figure to use in like cases should be determined from existing outlying suburbs in the subject area.

(6) *Promotion of Travel*: Advertising and routing of trips by travel agencies, advertisement of goods by shops, and other means of travel promotion have their effect on total travel and route of travel. US 301 through Maryland and Virginia has been growing rapidly in traffic volume in the last few years, and this abnormal growth has been ascribed in part to the practice of routing agencies in suggesting the use of US 301. From 1950 to 1953 inclusive, the use of US 1 by out-of-state cars increased by 40 percent at Ashland, Virginia, whereas the use of US 301 by out-of-state cars increased 110 percent at Hanover, just east of Ashland.

(7) *Decentralization of Homes and Industry and Consolidation of Schools*: No figures are available on effects of these actions, yet it is reasonable to assume that the traffic pattern is changed.

(8) *Tradition and Habit*: These may operate to prevent or delay changes in facility and travel pattern.

⁸ *Shopping Habits and Travel Patterns*. Special Report 11-B, Highway Research Board, Washington, D.C. 1955.

⁹ *Traffic Volume Trends—Their Use in Forecasting*. R. E. Livingston, 1953 Proceedings, W.A.S.H.O.

While forecasts of motor vehicle travel are commonly predicated upon historic trends, this provisional list of operative factors should be given consideration, if only of a qualitative nature, in the projection of trends into the future. They influence trends, and all factors which have some relationship should be correlated.

Projection of Component Trends: In terms of resulting reliability, composite projection and component projection may be likened, respectively, to random sampling and stratified sampling. For the same total sample a higher degree of accuracy is obtained from stratified sampling and from component projection.

The standard, or classic method of area-wide vehicle-mileage forecasting rests upon three basic determinants of equal weight:

1. Change in population (growth and distribution)
2. Change in persons-vehicle ratio (by vehicle type)
3. Change in average vehicle use (by vehicle type)

The choice of this method presupposes that historical data are available for each of these categories from which projections may be made. Upon the completion of projection of these individual determinants through the forecast period, the estimate of traffic for any particular future year within the forecast period may be obtained as follows:

(1) Project the trend of each of the three basic determinants to the particular year sought and obtain the ratio of the values thus found to the values of the respective determinants for a common base year (usually the present year, or the year for which the last traffic data are available); (2) obtain the product of these values, or ratios; (3) multiply the resulting product by the traffic (ADT or other value) for the common base year.

A curve may be developed showing the forecast for each year of the forecast period, since the projected trend may not be a straight line. This method of forecasting provides the framework which should be modified in accordance with the many combining operative factors, such as anticipated changes in highway system, congestion, competition and technology which may not be

reflected in a projection of historical trends of the three major determinants.

As a guide in extending the historical trends of the three determinants the following observations are offered:

1. *Change in population:* The U. S. Census Bureau has made forecasts for five-year periods for the continental United States through 1975 and for the individual states through 1960. These data provide low, medium and high values. The Vital Statistics Division of the State Health Department may be able to provide projections or, at least, historical trends in births and deaths. State planning boards and city planning commissions, and state and local school boards can provide helpful statistics.

The U. S. Census Bureau's forecast of population of the continental United States is given herewith (in thousands).

	<u>1955</u>	<u>1960</u>	<u>1965</u>	<u>1970</u>	<u>1975</u>
Low	164,403	173,847	180,927	189,110	198,632
Medium	164,644	176,126	186,146	196,269	206,615
Medium	—	—	—	202,359	213,568
High	164,782	177,426	189,916	204,222	220,982

The April, 1950 Census of population of continental United States was 150,697,361 (not including armed forces in foreign countries).

Where information is available, population forecasts may be made of the four determinants of population growth, namely:

- a. Births
- b. Deaths
- c. Immigration
- d. Emigration

Although the Pearl-Reed Curve is used or simulated in predictions for local areas by some forecasters, there is as yet no sure knowledge of the saturation point. Zoning laws and amount of land feasible for new dwelling units may give an indication of the saturation point in urban areas. Potential resources, including water and power supply, are important factors in migration or population shifts and growth.

2. *Change in Persons-Vehicle Ratio:* If data are available the forecast should be made by vehicle types, inasmuch as it is desirable to know the anticipated registration and mileage by type both for revenue forecasting and for design purpose. The truck registration has increased at a higher rate, generally, than the passenger car registration. The local trends and reasons should be studied in this component projection. The relative costs and service of the various modes of transportation play an important part in choice of mode and relative use.

In 1940, the ratio was 131,669,275 persons to 32,462,920 vehicles, or four and one-tenth persons per vehicle; in 1950, there were 150,697,361 persons and 49,161,691 vehicles, or three and six-hundredths persons per vehicle. In 1954, with an estimated population in the continental United States of 162,414,000, there were 48,498,870 passenger cars, 248,346 buses, and 9,842,647 trucks, a total of 58,589,863 vehicles or two and eight-tenths persons per vehicle.

As to the saturation point and its date, one can only surmise. California now registers a vehicle for each two and two-tenths residents and a passenger car for each two and four-tenths residents. There has been some thought that the limit for passenger cars will be reached with two cars per household. In 1950, there were about three and thirty-five hundredths persons per household. On this basis the limit would be one and seven-tenths persons per passenger car (it is an odd coincidence that the average occupancy of a passenger car is about one and seven-tenths). But in 1940, there were three and sixty-seven hundredths persons to a household.

While it is unlikely that the same reduction will hold for the next ten years, nevertheless there are indications that there will be some further reduction in number of persons per household. In 1953, for example, there were three and twenty-eight hundredths persons per household.

On a nationwide basis, it is unrealistic to set the limit so low or expect it to be reached within the reasonable forecast period. In New York City's Borough of Manhattan, because of economy of mass transit and lack of space for vehicles to move or park, there

were eight and five tenths persons per vehicle in 1950. In considering the various conditioning factors, it would seem that two persons per vehicle (all types) would be a limit hardly reached nation-wide in the next twenty years.

It has been predicted that there will be 85 million vehicles (including twenty million trucks and buses) registered in 1975²⁰ and a population between 198 and 221 million at that time, or an estimated two and three-tenths to two and six-tenths persons per vehicle. Other more optimistic predictions estimate 100 million vehicles by 1975, which would provide a vehicle for each 2.0 to 2.2 persons.

3. *Change in Average Vehicle Use:* In 1930 there was a total of 26,531,999 vehicles registered in the United States, and an estimated 206 billion miles of travel, or about 7,780 miles of travel per vehicle.

In 1940, there were 32,462,920 vehicles registered. For the same year there were about 302 billion vehicle miles of travel, or about 9,300 miles of travel per vehicle.

In 1950, there were 49,161,691 vehicles registered and 458 billion vehicle miles of travel, or about 9,310 miles of travel per vehicle.

In 1955, with a total of 61,834,702 vehicles registered and an estimated 595 billion vehicle miles of travel, there were about 9,620 miles of travel per vehicle.

The above figures disclose an increasing use of the motor-vehicle, but also reveal a decelerating rate of increase. Leisure time, economy, extent and physical conditions of highway facilities, and degree of congestion are important factors in vehicle usage. There is a difference in usage between urban and rural areas, and between autos and trucks. Suggested ceilings for 1985 range from 10,000 to 10,500 miles per vehicle.

In projecting the usage of vehicles, it is noted that the road system growth of the twenties, the depression of the thirties, and the restriction of gasoline and tires during World War II had their effect on vehicle usage. Because there is so little of "un-

²⁰ 1952 Report of President's Material Commission.

disturbed sample" to project it is difficult to predict usage with any high degree of assurance.

If, for the moment, the following estimated values are accepted for 1975, the index for that year in terms of 1950 may be determined.

	1950	1975	Ratio
1. Population (thousands)	150,697	210,000	1.39
2. Persons per vehicle	3.06	2.2	1.39
3. Average use of vehicle	9,310	10,500	1.13

Multiplying the ratios of items one, two, and three together, the index to be applied to 1950 travel to obtain the estimated 1975 travel is calculated as $1.39 \times 1.39 \times 1.13 = 2.18$ or more than double the 1950 travel (458 billion \times 2.18 = 1,000 billion vehicle miles in 1975). These figures are shown to illustrate the method and do not necessarily represent a forecast of travel.

Resuming the discussion of usage projection, it is suggested that usage be determined for passenger cars, trucks and buses. At present, of the total motor-vehicle travel in the United States, eighty percent is done by passenger cars, nineteen percent by trucks, and one percent by buses. This proportion does not exist on all routes nor is it maintained year by year. Travel by truck combinations has been increasing at a rate about five times as fast as by passenger cars in the last twenty years.

Another breakdown of travel may be in terms of purpose of travel. Essential travel (work, business and shopping) is fairly stable and related firmly to population and economy. Non-essential travel (recreational and tourist) has grown with growth of leisure and consumer purchasing power. Nonessential travel is more easily diverted to new routes than essential travel. In other words, it responds to promotion. Vacation travel is now reputed to be the fourth largest industry and has grown fifty percent since 1940. Nearly one half of all U. S. families took one or more vacation trips in 1952-53 and eighty-three percent travelled by car.¹¹ About twenty-eight million trips were made of 978 miles average length.

¹¹ *The Travel Market of the United States, 4th Nationwide Survey*. The Curtis Publishing Co. 1950.

A variant¹² of the classic method for forecasting passenger car travel makes use of the following determinants which substitute for the determinants of the classical method:

1. Change in driver population
2. Change in number of drivers per car
3. Change in average vehicle use

As in the standard procedure, ratios of a specific future year to a given base year are determined, and the quotients of these three ratios used as factors to obtain the index of change or growth.

$$\text{Then } V_n = V_o \left(\frac{D_n \cdot R_n \cdot U_n}{D_o \cdot R_o \cdot U_o} \right)$$

where:

- V_n = traffic for future year
- D_n = driver population for future year
- R_n = ratio of cars to drivers for future year
- U_n = average car use for future year
- V_o = traffic for base year
- D_o = driver population for base year
- R_o = ratio of cars to drivers for base year
- U_o = average car use for base year

“Driver population” is not analogous to “eligible age group” but may actually be nearer 60 percent of the eligible group. In states where driver licenses must be renewed periodically, statistics on driver population may be readily obtained. If the relation is desired, these data may be compared to the respective total population by age, race, and sex to provide a reference for probable changes in driving population in future years.

With reference to drivers per passenger car, this ratio in California is presently one and thirty-two hundredths drivers per car, and seems to be approaching one and twenty-five hundredths as a probable limit. This limit, in terms of total population, would be about two and twenty-five hundredths persons per *passenger car*.¹³ Thus, if the ratio of trucks and buses to the total registration is one to five, it will be seen that the limit will be one and eight-tenths persons per vehicle—in California—where there are now two and two-tenths persons per vehicle.

In Nevada and Wyoming in 1952 there were two persons per vehicle, and two and one-tenth in Idaho, Montana and North

¹² F. Houston Wynn, letter of April 7, 1954 to J. D. Carroll, Jr.

¹³ F. Houston Wynn. *Ibid.*

Dakota. In the District of Columbia, an urban metropolitan area, the persons per vehicle ratio was the highest at four and four-tenths and in Mississippi the second highest at four and two tenths. The national average was three persons per vehicle.

Locally for a specific traffic corridor, where the classic method may not serve, there remains the method of projection of the components of the traffic stream in terms of diversion, generation, and trends of composition.

Expansion of Existing Patterns: The existing travel pattern can be developed from data obtained in a metropolitan area origin and destination survey. In order to plan and construct the most effectual traffic arteries and terminals for the years ahead, it becomes desirable to expand the existing pattern to some specific future year. With both patterns at hand a guide in direction and magnitude is provided for the ideal location and design of new facilities, or for the master transportation plan.

In some instances a projection of historic growth in traffic has been made and the index of growth thus found applied uniformly throughout the whole city area, and each zone movement multiplied by the same expansion factor.

However, it is known that unequal density and shifts of population, establishment of new business, industry or markets, and creation of new recreation or education centers cause differential growth in the traffic pattern, and negate the validity of a uniform expansion.

For example, if a certain zone has already reached the saturation point in housing then the change in population in that zone may be due chiefly to excess of births over deaths. On the other hand in the presently undeveloped suburban areas, the development of new housing will be the determinant of population, and the change in this zone may be due to immigration.

It is known that the urban fringe areas are being populated faster than the central city, and provide more automobile trips per dwelling unit than the central city. It is also known that vehicle mileage in the fringe areas is growing at a faster rate than in the city where travel is choked by congestion.

It is of interest that, whereas the thirtieth highest hour in traffic volume in the rural areas averages about fifteen percent of the

annual average daily traffic, this same hour may average twelve percent at the urban periphery, ten percent in the intermediate urban area, and eight percent or less in the central business district. This decrease in thirtieth highest hour values shows the effect of congestion and differences in urban and rural travel.

These facts all argue that a single expansion factor will not serve universally in an urban area. Various methods have been developed to provide a more realistic differential expansion.

It is not the purpose of this manual to advise methods of projecting land use. Zoning laws, topography, existing ecology, artificial restrictions or barriers, tradition, transport media and convenience, and a host of other factors enter into urban expansion. City planners, realtors, chambers of commerce, and other agencies interested in city services such as communication and transportation, can be of help in defining the shape and size of the future urbanized area in terms of population, commerce, and industry.

When this organism has been defined quantitatively, zone by zone, for some future date, factors may be derived by determining the ratio of population, or commerce, or industry, or other traffic generators for the specific future year in terms of a given base year.

A method developed by the Minnesota State Highway Department in cooperation with the U.S. Bureau of Public Roads is explained in an interdepartmental memorandum of the Bureau from Mr. W. V. Buck, Division Engineer, Kansas City, Missouri to Mr. H. S. Fairbank, Deputy Commissioner, Washington, D.C. under date of November 10, 1953. The memorandum is of interest:

Div. 5—Bureau of Public Roads

Mr. H. S. Fairbank
Deputy Commissioner
Washington, D.C.

November 10, 1953

W. V. Buck
Division Engineer, Kansas City, Missouri

Minnesota—Minneapolis—St. Paul Metropolitan Area Traffic Study

The methods and procedures by which the State proposed to project the

1949 traffic data from the above referenced study to the year 1970 and make traffic route assignments were discussed in the attachments in our April 23, 1952 and August 3, 1953 memoranda to you.

That analysis which is now nearing completion was reviewed with the State by Mr. Swanson during his visit to St. Paul on October 23. Inasmuch as some minor improvements and refinements were incorporated into the analysis as it progressed, we have summarized and explained by numbered paragraphs the various steps actually followed in that analysis.

1. Each of the incorporated areas and suburbs within the study area was considered separately in estimating the 1970 expansion factor.
2. The corporate areas of Minneapolis and St. Paul were further broken down into origin-destination study districts.
3. Minneapolis and St. Paul planning officials furnished the State with the following land use factors for each O-D study district:

$$\text{Dwelling unit factor} = \frac{\text{estimated 1970 dwelling units}}{1949 \text{ dwelling units}}$$

$$\text{Commercial factor} = \frac{\text{estimated 1970 commercial developments}}{1949 \text{ commercial developments}}$$

Both of these cities have excellent planning officials and they spent considerable time, study and research in the development of the above factors.

4. For each of the other incorporated areas and suburbs within the study area the State in co-operation with local officials compiled the following information: Number of dwelling units in 1949 and 1970, number of commercial establishments in 1949 and 1970, and the dollar volume of sales in 1949 and 1970.

5. The dwelling unit factor for the area described in paragraph (4) was computed in the same manner as for Minneapolis and St. Paul. The commercial factor was the ratio of the estimated number of commercial establishments in 1970 to the number of such establishments in 1949. The possibility of using dollar volume of sales in computing the commercial factor was considered but a special investigation indicated there was a greater relationship between trips and number of commercial establishments than to dollar volume of sales.

6. Expansion factors for the year 1970 were computed for the trips through the external cordon stations. The 1970 traffic volumes were estimated by studying the trends from traffic counts from 1947 through 1952 at those stations. Considering the external cordon line as forming a circle, a number of stations falling on a sector of that circle were considered as a group and therefore had the same expansion factor.

7. The tabulating cards were sorted to give the number of 1949 trips to each district (paragraphs 1 and 2) for "residential" (social-recreational, school, serve passenger, and home) and "commercial" (work, business, medical-dental, eat meal, shopping) purposes.

8. The 1970 trips to and land use factor for each of these districts were estimated as follows:

- a. Dwelling unit factor times 1949 "residential trips" equals 1970 "residential trips"
- b. Commercial factor times 1949 "commercial trips" equals 1970 "commercial trips"
- c. 1970 trips equals a plus b
- d. Land use factor equals $\frac{1970 \text{ trips}}{1949 \text{ trips}}$

9. The tabulating cards were sorted to summarize the 1949 inter-district, district-external station, and external station-external station trips.

10. The trips computed from the preceding paragraph were expanded to 1970 volumes by a trip factor which was the average of the land use factor (paragraph 8d) and/or external station factors (paragraph 6) pertinent to the trip movement studied.

11. The 1949 intradistrict trips were expanded to 1970 volumes on the basis of the land use factor for that district.

12. The sum of the 1970 trips from paragraphs 10 and 11 represented the total estimated 1970 trips.

13. The trips from paragraph 12 were then analyzed by district of destination. These in turn were compared with the "to" district trips computed on the basis of the land use factor for that particular district (paragraph 8c). If all analysis assumptions had been theoretically correct, this ratio would be unity. However, this was not so. The ratio of trip destinations computed by the trip factor (paragraph 10) to the trip destinations computed by the land use factors (paragraph 8) by districts was surprisingly good. For 45 of the 60 districts the ratio was less than 15 percent from unity. For 15 of the districts the ratio was less than 85 percent, the minimum being 74 percent. The low ratios were found to be in outlying areas probably because insufficient consideration was given to the distributional traffic pattern in developing areas. The ratio in the central business districts of both Minneapolis and St. Paul was approximately 1.0.

14. For those districts in which the ratio was less than 0.85, sufficient trips were added to bring the ratio about one half way up from its existing ratio towards unity.

From the information developed under paragraph 10, the distributional pattern of 1970 trips was tabulated by subzone of origin and destination for trips with destinations to each such district. New tabulating cards were added to the deck providing the same distributional pattern and in sufficient number to bring the ratio up as previously indicated. The addition of these cards increased the comparative ratio in other districts but only to a minor extent.

15. Thus far no recognition has been given in the analysis to proposed or probable large-scale shopping centers. The steps outlined in the following numbered paragraphs 16 and 17 describe how the ratios which had been previously raised halfway to unity were now raised to approximate unity in recognition thereof.

16. The large shopping areas in existence in 1949 were determined by analysis of the basic tabulating cards. The subzones of origins of all trips to selected large shopping areas were tabulated and the data therefrom plotted on maps. The distributional pattern from each of those shopping areas was studied and a determination made of those trips which might possibly be diverted (although no actual diversion was made) to new shopping areas in the outlying areas. This determination was made on the basis of engineering judgment considering such factors as travel time and distance and street layout.

In studying the distributional pattern of existing large shopping areas (including the central business districts) it was noted that 70 percent of all trips to Sears were less than 3 miles in length and 84 percent of all trips to Montgomery Ward less than 5 miles in length. The traffic to Sears showed a predominantly north-south distribution and to Ward's an east-west distribution. A study of the locations of these stores with respect to the street and highway network indicates the reasons for such distribution.

17. New tabulating cards representative of potential trips to the new shopping areas were added to the basic deck in sufficient numbers to bring the ratio of the number of trip destinations as computed from the trip factor and land use factor, respectively, to approximately 1.0. The origins of these trips were estimated from the study outlined in the preceding paragraph.

18. The total number of 1970 trips estimated in accordance with numbered paragraphs 10, 14, and 17 were sorted by district of origin and destination.

19. The 1970 expansion factor for the 1970 intradistrict movement was the ratio of the 1970 trips estimated in accordance with paragraph 18 to the actual 1949 trips.

20. The 1970 expansion factor for intradistrict trips was the land use factor for that district.

IRA E. TAYLOR

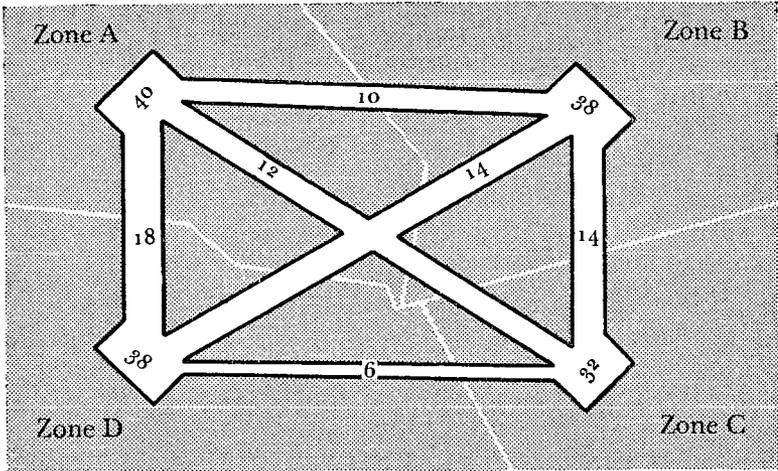
For Division Engineer

A second method developed for translating existing travel patterns into future patterns when the growth factors of the several zones have been forecast is that described in the article titled "Vehicular Trip Distribution by Successive Approximations" by Thomas J. Fratar, published in "Traffic Quarterly" in January 1954.

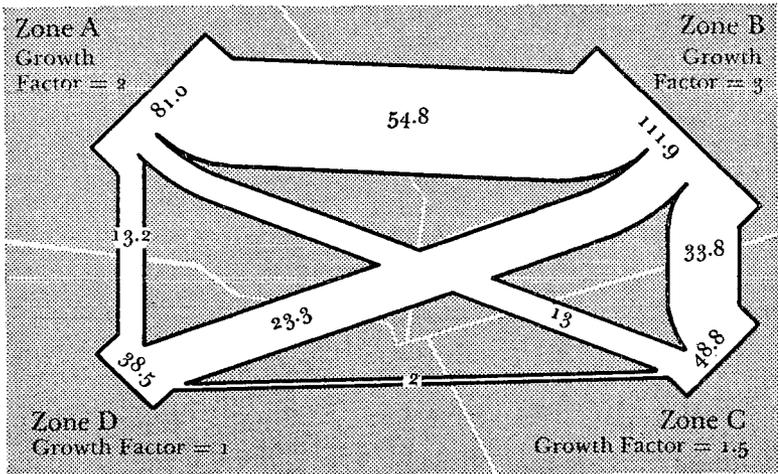
The mechanics of the method are as follows:

III. Example of Proposed Method

The following computations for a simple four-zone problem illustrate the proposed procedure. The situation is shown in Figure V-4 and is summarized in the following pages.



Distribution of Existing Trips



Distribution of Future Trips (as found by four approximations)

FIGURE V-4. Four zone problem.

SOURCE: T. J. Fratar, Traffic Quarterly, January 1954.

PRESENT NUMBER OF INTERZONAL TRIPS

<i>Zones</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
A	—	10	12	18
B	10	—	14	14
C	12	14	—	6
D	18	14	6	—
	<hr/>	<hr/>	<hr/>	<hr/>
Present Totals	40	38	32	38
Estimated Future Totals	80	114	48	38
Growth Factors	2	3	1.5	1

(Ratio of Present Totals to Future Totals)

For zone A the future traffic volume of 80 trips would be distributed to the interzonal movements AB, AC and AD in proportion to the attractiveness of those movements at A; and for zone B the future traffic volume of 114 trips would be similarly distributed to interzonal movements AB, BC and BD according to the attractiveness of those trips at B. The volume of AB in each case would be:

$$\frac{\text{The future trips into and out of the zone considered (A or B)} \times \text{existing trips along AB} \times \text{growth factor of opposite zone}}{\text{Sum of products of existing trips of the zone considered (A or B) and the respective opposite growth factors}}$$

The distribution to AB at A would be:

$$\frac{80 \times 10 \times 3}{10 \times 3 + 12 \times 1.5 + 18 \times 1} = 36.4$$

and the distribution to AB at B would be:

$$\frac{114 \times 10 \times 2}{10 \times 2 + 14 \times 1.5 + 14 \times 1} = 41.5$$

Computations for the first approximation for each of the four zones are summarized below. Line 1 for each summary shows the existing trips for the indicated interzonal movement. Line 2 shows for each zone the interzonal trips multiplied respectively by the growth factor of the other zone involved. These products are summarized for each zone to provide a common denominator

for the distribution of trips of that zone. This distribution is accomplished by dividing the common denominator into the total trips desired for the zone, and multiplying the quotient by the products shown in line 2. The new distribution, shown in line 3, necessarily adds up to the total number of trips desired for the zone.

FIRST APPROXIMATION

<i>Zone</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>Sum of Products of Trips and Growth Factors</i>	<i>Desired New Total Trips</i>	<i>Ratio of Desired New Total Trips to Sum of Products</i>
Growth Factor	2	3	1.5	1			
<i>For Zone A</i>							
(1)	-	10	12	18			
(2)	-	30	18	18	66	80	1.21
(3)	-	36.4	21.8	21.8	80		
<i>For Zone B</i>							
(1)	10	-	14	14			
(2)	20	-	21	14	55	114	2.07
(3)	41.5	-	43.5	29.0	114		
<i>For Zone C</i>							
(1)	12	14	-	6			
(2)	24	42	-	6	72	48	.667
(3)	16.0	28.0	-	4.0	48		
<i>For Zone D</i>							
(1)	18	14	6	-			
(2)	36	42	9	-	87	38	.437
(3)	15.8	18.3	3.9	-	38		

The pairs of interzonal volumes obtained by these computations are averaged as shown below to obtain the first approximation for interzonal trips.

	<i>A-B</i>	<i>A-C</i>	<i>A-D</i>	<i>B-C</i>	<i>B-D</i>	<i>C-D</i>
	36.4	21.8	21.8	43.5	29.0	3.9
	41.5	16.0	15.8	28.0	18.3	4.0
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
First	77.9	37.8	37.6	71.5	47.3	7.9
Approximations	39.0	18.9	18.8	35.7	23.6	4.0

The averages for the trips radiating from each zone are next summarized to determine new growth factors to be used in the second approximation as shown below.

	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
	39.0	39.0	18.9	18.8
	18.9	35.7	35.7	23.6
	18.8	23.6	4.0	4.0
	<hr/>	<hr/>	<hr/>	<hr/>
New Totals	76.7	98.3	58.6	46.4
Desired Totals	80.0	114.0	48.0	38.0
	<hr/>	<hr/>	<hr/>	<hr/>
New Growth Factors	1.04	1.16	.82	.82

Additional cycles of approximations and corrections could be made as shown below.

SECOND APPROXIMATION

<i>Zone</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>Sum of Products of Trips and Growth Factors</i>	<i>Desired New Total Trips</i>	<i>Ratio of Desired New Total Trips to Sum of Products</i>
New Growth Factors	1.04	1.16	.82	.82			
<i>For Zone A</i>							
(1)	-	39.0	18.9	18.8			
(2)	-	45.3	15.5	15.4	76.2	80	1.05
(3)	-	47.5	16.3	16.2	80		
<i>For Zone B</i>							
(1)	39.0	-	35.7	23.6			
(2)	40.5	-	29.3	19.7	89.5	114	1.275
(3)	51.6	-	37.3	25.1	114		
<i>For Zone C</i>							
(1)	18.9	35.7	-	4.0			
(2)	19.7	41.4	-	3.3	64.4	48	.746
(3)	14.7	30.8	-	2.5	48		
<i>For Zone D</i>							
(1)	18.8	23.6	4.0	-			
(2)	19.6	27.4	3.3	-	50.3	38	.755
(3)	14.7	20.7	2.6	-	38		

	<i>A-B</i>	<i>A-C</i>	<i>A-D</i>	<i>B-C</i>	<i>B-D</i>	<i>C-D</i>
	47.5	16.3	16.2	37.3	25.1	2.5
	51.6	14.7	14.7	30.8	20.7	2.6
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	99.1	31.0	30.9	68.1	45.8	5.1
Second Approximations	49.6	15.5	15.4	34.0	22.9	2.5
		<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	
		49.6	49.6	15.5	15.4	
		15.5	34.0	34.0	22.9	
		15.4	22.9	2.5	2.5	
		<hr/>	<hr/>	<hr/>	<hr/>	
New Totals		80.5	106.5	52.0	40.8	
Desired Totals		80.0	114.0	48.0	38.0	
		<hr/>	<hr/>	<hr/>	<hr/>	
New Growth Factors		1.0	1.07	.92	.93	

THIRD APPROXIMATION

<i>Zone</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>Sum of Products of Trips and Growth Factors</i>	<i>Desired New Total Trips</i>	<i>Ratio of Desired New Total Trips to Sum of Products</i>
New Growth Factors	1.0	1.07	.92	.93			
<i>For Zone A</i>							
(1)	-	49.6	15.5	15.4			
(2)	-	53.0	14.2	14.3	81.5	80	.982
(3)	-	52.0	13.9	14.1	80		
<i>For Zone B</i>							
(1)	49.6	-	34.0	22.9			
(2)	49.6	-	31.3	21.3	102.2	114	1.114
(3)	55.4	-	34.9	23.7	114		
<i>For Zone C</i>							
(1)	15.5	34.0	-	2.5			
(2)	15.5	36.4	-	2.3	54.2	48	.887
(3)	13.7	32.3	-	2.0	48		
<i>For Zone D</i>							
(1)	15.4	22.9	2.5	-			
(2)	15.4	24.5	2.3	-	42.2	38	.90
(3)	13.8	22.1	2.1	-	38		

	<i>A-B</i>	<i>A-C</i>	<i>A-D</i>	<i>B-C</i>	<i>B-D</i>	<i>C-D</i>
	52.0	13.9	14.1	34.9	23.7	2.0
	55.4	13.7	13.8	32.3	22.1	2.1
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	107.4	27.6	27.9	67.2	45.8	4.1
Third Approximations	53.7	13.8	14.0	33.6	22.9	2.0
		<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	
		53.7	53.7	13.8	14.0	
		13.8	33.6	33.6	22.9	
		14.0	22.9	2.0	2.0	
		<hr/>	<hr/>	<hr/>	<hr/>	
New Totals		81.5	110.2	49.4	38.9	
Desired Totals		80.0	114.0	48.0	38.0	
		<hr/>	<hr/>	<hr/>	<hr/>	
New Growth Factors		.98	1.035	.973	.98	

FOURTH APPROXIMATION

<i>Zone</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>Sum of Products of Trips and Growth Factors</i>	<i>Desired New Total Trips</i>	<i>Ratio of Desired New Total Trips to Sum of Products</i>
New Growth Factors	.98	1.035	.973	.98			
<i>For Zone A</i>							
(1)	-	53.8	13.8	14.0			
(2)	-	55.7	13.4	13.7	82.8	80	.967
(3)	-	53.8	13.0	13.2	80		
<i>For Zone B</i>							
(1)	53.8	-	33.6	22.9			
(2)	52.7	-	32.7	22.5	107.9	114	1.055
(3)	55.7	-	34.5	23.8	114		
<i>For Zone C</i>							
(1)	13.8	33.6	-	2.0			
(2)	13.5	34.8	-	2.0	50.3	48	.953
(3)	12.9	33.1	-	2.0	48		
<i>For Zone D</i>							
(1)	14.0	22.9	2.0	-			
(2)	13.7	23.7	2.0	-	39.4	38	.965
(3)	13.2	22.8	2.0	-	38		

	<i>A-B</i>	<i>A-C</i>	<i>A-D</i>	<i>B-C</i>	<i>B-D</i>	<i>C-D</i>
	53.8	13.0	13.2	34.5	23.8	2.0
	55.7	12.9	13.2	33.1	22.8	2.0
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
Fourth	109.5	25.9	26.4	67.6	46.6	4.0
Approximations	54.8	13.0	13.2	33.8	23.3	2.0
		<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	
		54.8	54.8	13.0	13.2	
		13.0	33.8	33.8	23.3	
		13.2	23.3	2.0	2.0	
		<hr/>	<hr/>	<hr/>	<hr/>	
New Totals		81.0	111.9	48.8	38.5	
Desired Totals		80.0	114.0	48.0	38.0	
		<hr/>	<hr/>	<hr/>	<hr/>	
New Growth Factors		.99	1.02	.985	.985	

For this simple four-zone problem, the maximum difference for any zone between the desired total number of trips and the adjusted total was about 3.5 percent at the end of the third cycle and about 2 percent at the end of the fourth cycle. Each successive cycle reduced the difference by about one half.

As can be seen from this example, manual procedures are entirely impracticable for other than extremely simple problems like the one illustrated. However, it can also be seen that the procedures are repetitious and each is in itself relatively simple. Because of this, an extensive problem of any conceivable complexity can be readily set up for rapid analysis by business machine methods.

Summary of the Method

1. The first step is the preparation of dependable estimates of the total number of automobile trips that can be expected to enter and leave each traffic zone of the area under study at the future date for which the distribution is desired. These estimates must have a possible distribution—no one zone can have more trips into and out of it than enter and leave all the other zones combined.
2. The total trips of each zone are distributed to the other zones

in proportion to the attractiveness indicated by existing interzonal volumes and by the anticipated growth of each of the other zones.

3. The distribution of trips for all zones will produce two tentative values for each interzonal movement. These pairs of tentative values are averaged to obtain the first approximation of the interzonal volumes.
4. For each zone, the sum of the first approximation volumes is divided into the total volume desired for the zone to obtain first approximation growth factors to be used in the computations for the second approximations.
5. The originally estimated trips for each zone are again distributed to interzonal movements, these new assignments being in proportion to the interzonal volumes and growth factors obtained by the first approximation. The pairs of tentative volumes obtained by this distribution are averaged as before, and the process repeated until the desired conformity is obtained.

IV. Comparison with Average Factor Method

If it is determined that the trips into and out of a zone will change in a definite way, the proposed method will provide a solution compatible with the anticipated change. For the four-zone example described above, the results by the method of successive approximations and by the method of averaging growth factors would be as follows:

ESTIMATED INTERZONAL TRIPS

	<i>A-B</i>	<i>A-C</i>	<i>A-D</i>	<i>B-C</i>	<i>B-D</i>	<i>C-D</i>
Computed at end of Fourth Approximation by successive approximation method	54.8	13.0	13.2	33.8	23.3	2.0
Computed by method of Averaging Growth Factors	25.0	21.0	27.0	31.5	28.0	7.5

and the totals for the zones would be:

	A	B	C	D
Desired Totals	80	114	48	38
Totals at the end of Fourth Approximation by successive approximation method	81	111.9	48.8	38.5
Totals which would be obtained by the method of averaging growth factors	73	84.5	60	62.5

For this example the totals obtained by the method of averaging growth factors is at considerable variance with the respective totals desired. The future volume of Zone D, for example, was increased about 90 percent by the averaging method, although the total volume of Zone D is expected to remain unchanged.

c. *Synthesis of Hypothetical Patterns*: This method¹⁴ constructs a hypothetical structure of movement—an idealized pattern for some specified future date. The validity of the method rests upon the stability and conformity of traffic patterns. Wynn found in his studies of traffic patterns during a period of four years (1950–1954) and in the studies of twenty collaborating students that “there is continuity of pattern in the travel performed in every urban area . . . a distinct set of trip-generating characteristics for each land use and for each mode of travel.

“Where an origin and destination study exists, the basic patterns of trip generation by mode and land use can quickly be determined and applied to estimates of future population distribution to show future traffic demands . . . the basic principles of trip distribution are employed rather than an arbitrary expansion factor.”¹⁵

Use is made of analogy, and the patterns created by a selected city serve as a prototype. The character and intensity of land use in zone of origin and zone of destination, the distance between origin and destination, the level of economy, the available modes of transportation—these provide the correlating factors to determine the magnitude of travel between any two given zones.

¹⁴ See Chapter II for details.

¹⁵ F. Houston Wynn. *Ibid.*

Using this method, hypothetical models can be constructed for future travel patterns where little or no travel now exists. Not suggested as a substitute for origin and destination surveys, the method gathers its building blocks from an existing origin and destination survey and builds an annex thereto.

The particular promise for this method is to permit estimates for the urban fringe areas where no pattern exists at the moment but which will, it is anticipated, be built up in the near future.

Merging the Expanded and Synthetic Patterns: While it appears desirable to use the travel patterns of origin and destination surveys and expand them to a future date by some appropriate method, yet it also appears desirable to manufacture a pattern for the fringe areas undeveloped at the time of the O and D survey. It therefore becomes necessary to merge an expanded O and D survey with a synthetic pattern. A method is outlined in a memorandum from M. E. Campbell to J. D. Carroll, Jr. prepared in March 1954. An excerpt follows:

It appears that a combination of Fratar and Wynn procedures may provide an acceptable method of developing and redistributing the 1980 traffic.

Wynn's method would be used to determine the probable traffic pattern for zones now vacant or with little development and for certain areas where there is little or no traffic interchange between certain traffic zones.

When the total 1980 growth is predicted for a zone now having relatively little land use, the Wynn method may be used to obtain the magnitude and distribution of travel from this zone to other zones. Suppose, for example, that zone Q, Fig. V-5, is vacant in 1954 but is predicted to produce substantial vehicle trips in 1980. Assume also that zones A, B, C, D, E and F exist now, and each has substantial vehicle trips and a stable travel pattern in 1954.

To simplify the mechanics, let us deal with the new zone Q and old zone B for the moment and portray them graphically as follows:

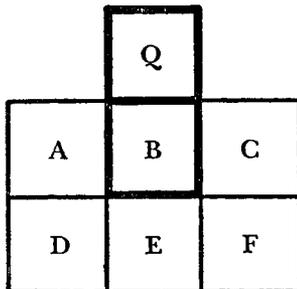


FIGURE V-5.

Assume that the Wynn method forecasts a potential of 500 trips for 1980 for zone Q and that 100 of these are interchanging with zone B.

Let us look at zone B. In examining the 1954 pattern we discover that 10 percent of its traffic interchanges with A, 20 percent with D, 30 percent with E, 20 percent with F and 20 percent with C. Suppose that the 1954 traffic volume of zone B is 200 trips per day, and the 1980 potential is 500 trips.

Taking these patterns one at a time, we have for zone Q:

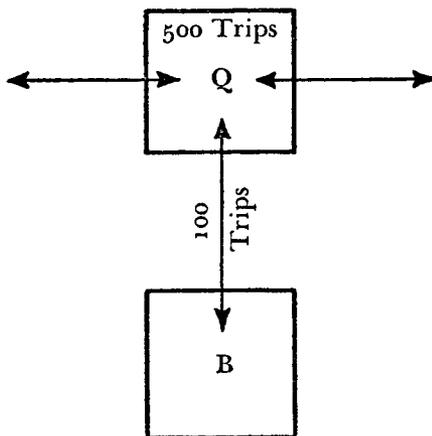


FIGURE V-6. Wynn pattern for 1980.

And for zone B:

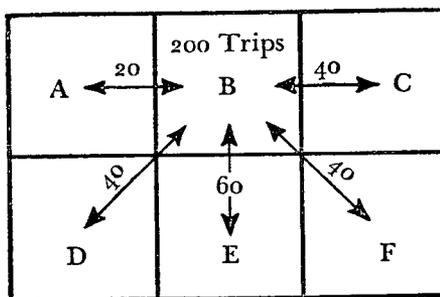


FIGURE V-7. Existing pattern—200 trips.

We wish to merge the two patterns and derive an over-all 1980 pattern. It is seen at once that the present distribution of trips from zone B must be modified when we add an interchange of 100 trips with zone Q. The following method is suggested:

Since 100 trips are to interchange between zones Q and B, and the potential trips in zone B are 500, this would leave 400 trips to interchange

between zone Z and zones A, D, E, F and C. Hence, these movements which totalled 200 in 1954 would total 400 in 1980, with a growth factor of 2.0 indicated for this portion of zone B trips. Note that the over-all growth factor of 2.5 is *not* applicable.

Using the 1954 pattern for this portion and a growth factor of 2.0, the Fratar method of redistribution of trips is used for this portion of trips to obtain the 1980 pattern. Next, the "Wynn Component" is added to complete the 1980 pattern.

Summarizing, determine for pertinent zones the interchange as calculated by the Wynn method. Deduct this from the potential trips in zones affected. The remainder is used to determine the growth factor of the 1954 pattern. Apply the Fratar method to redistribute the 1954 pattern. Then add the Wynn increment.

Checking the Forecast: An examination of growth characteristics of a city discloses that the cordon count around the central business district does not parallel the population or activity growth. Also, a degree of balance must be maintained between population and such activities as manufacturing and marketing so long as a desirable economy is maintained. These factors are significant in the synthesis of a hypothetical travel pattern. Therefore, when the component parts of the pattern of the future are put together, they should be checked for balance, for over-all traffic generation and for CBD generation. An examination of other cities of a size comparable to the projected size of the subject city will indicate the relation of the components.

The following method is suggested as one type of check that may be made. Essentially it consists of distributing the total generation of the CBD among the zones contributing thereto in accordance with their population, distance and direction from the CBD. The distribution presupposes a cordon count forecast. This may be appropriated from some other analogous city which has already reached the size forecast for the subject city. Also to be borrowed from the analogous city is the percentage of traffic diagram shown in Figure V-8.

Distribution to zones within each ring is proportional to the which, entering the city through the external cordon, is counted in the inner CBD cordon.

The mechanics of the method may be illustrated by using the ratio of zone population to ring population. Traffic at the ex-

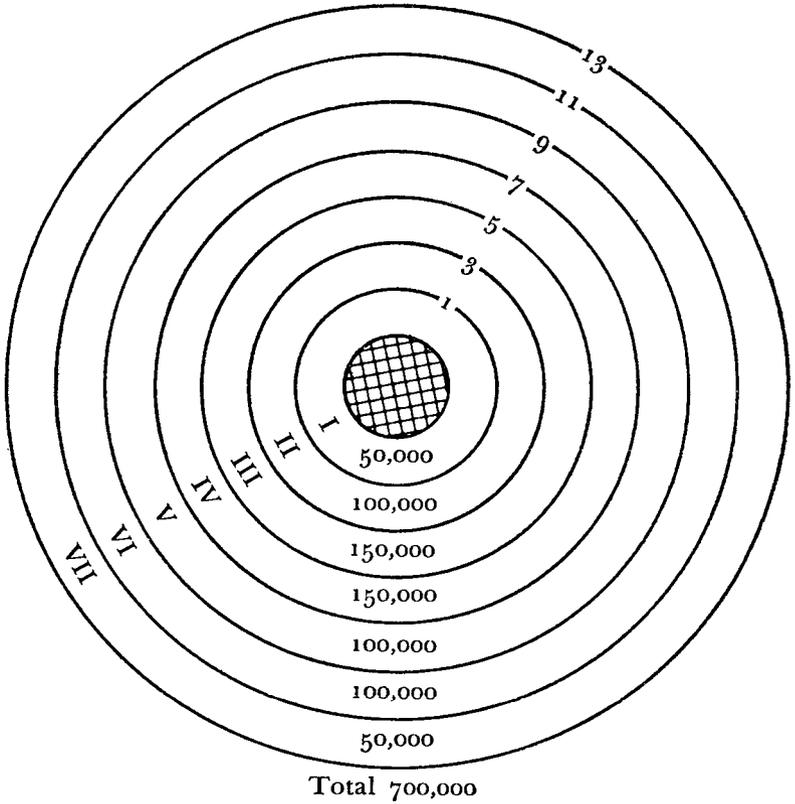


FIGURE V-8.

Assumption

Ring No.	<i>Assumed Generation to CBD per 1000 population</i>	<i>Total Assumed Generation</i>	<i>Adjusted $\frac{143,000}{130,000} = 110\%$</i>
I	100	5,000	5,500
II	300	30,000	33,000
III	250	37,500	41,250
IV	200	30,000	33,000
V	150	15,000	16,500
VI	100	10,000	11,000
VII	50	2,500	2,750
Total		130,000	143,000

Forecast Cordon (excluding external component) = 143,000

ternal stations may be projected from historical trends correlated with city growth.

The above illustration suggests one of many checks that may be applied to forecasts. Whenever it is possible to make forecasts by more than one method, a check is provided. Since forecasting is an art involving so many variable and intangible factors, as many checks as possible should be applied. Finally, view the whole and the parts in perspective for reasonableness of proportion between the interrelated parts and size of the composite.

Case Studies of Traffic Growth: Examples of growth will be found in Appendix A which includes information relating to bridges and roads.

SELECTED REFERENCES FOR SUPPLEMENTAL READING

1. Braff, Lloyd M. *A Comprehensive City Traffic Plan*. Proceedings, Institute of Traffic Engineers. 1952.
2. Carril, Ramiro Ramirez. *Traffic Forecast Based on Anticipated Land Use and Current Travel Habits*. Proceedings, Highway Research Board. 1952.
3. *Expressways*, City Planning Commission, Kansas City. Missouri. 1951.
4. *Comprehensive Express Highway Report, Greater Kansas City. Methods for Projection and Expansion of 1944 Origin-Destination Survey Data*. Missouri State Highway Commission. 1949.
5. *Airline Passengers*. Airport Planning. 1951. Civil Aeronautics Administration, U.S. Department of Commerce. U.S. Government Printing Office, Washington, D.C.
6. *Population Growth in Standard Metropolitan Areas, 1900-1950*. Housing and Home Finance Agency. U.S. Government Printing Office, Washington, D.C.
7. Fratar, Thomas J. *Vehicular Trip Distribution by Successive Approximations*. Traffic Quarterly. January 1954. Eno Foundation.
8. Holmes, E. H. *What's Ahead in Traffic Volumes*. Proceedings, Institute of Traffic Engineers. 1950.
9. Holmes, E. H. *Traffic to Come*. Paper at National Safety Congress. 1951.
10. *Detail of Procedures Used for Revision of Major Thoroughfare Network and Planning a Network of Expressways*. City of Dallas, Traffic Control Department. 1953.
11. *Virginia's Highway Needs*. Virginia Department of Highways. 1954.

12. *Toll Roads for the Richmond-Petersburg Area*. Wilbur Smith and Associates, New Haven, Connecticut. 1953.
13. Grant, Eugene L. *Principles of Engineering Economy*. The Ronald Press Company, New York. 1930.
14. *Estimates of Future Population of the United States, 1940-2000*. National Resources Planning Board, U.S. Government Printing Office, Washington, D.C. 1943.
15. *Growth Pattern of Cities*. Studies in Business Economics No. 39. National Industrial Conference Board, Inc. 247 Park Avenue, New York, N.Y. 1953.
16. *Illustrative Projections of the Population of the United States, by Age and Sex, 1955-1975*. U.S. Bureau of the Census, U.S. Government Printing Office, Washington, D.C., Series P-25 No. 78.
17. *Nationwide Highway Finance (Section 13) Study*. Circular Memorandum to Division Engineers from H. S. Fairbank, Deputy Commissioner Bureau of Public Roads, Washington, D.C. July 15, 1954.
18. Dorn, H. F. *Pitfalls in Population Forecasts and Projections*. Journal of the American Statistical Association. 1950.
19. *Population of the United States—Past and Projected*. American Telephone and Telegraph Company, New York. 1953.
20. *Population Trends*. Bureau of Agricultural Economics, U.S. Department of Agriculture, Washington, D.C. 1952. Mimeo.
21. *United States Population 1800-2050*. National Industrial Conference Board, Inc. 247 Park Avenue, New York, New York. 1953.
22. *Growth Patterns in Industry*. Studies in Business Economics No. 32. National Industrial Conference Board, Inc. 247 Park Avenue, New York, New York.
23. *Forecasting Business Trends*. Steel, the Weekly Magazine of Metalworking, June 29, 1953.
24. *Economic Indicators*. U.S. Congress, Joint Committee on the Economic Report (83rd Congress 2d session, Aug. 1954) U.S. Government Printing Office. Washington, D.C.
25. *American Capital Requirements—Estimates for 1946-1960*. U.S. Department of Commerce, Office of Business Economics, U.S. Government Printing Office, Washington, D.C. 1951.
26. Siegel, I. H. *Technological Change and Long-Run Forecasting*. The Journal of Business of the University of Chicago. July 1953.
27. *National Income and Product of the United States, 1929-1950*. U.S. Department of Commerce, Office of Business Economics. U.S. Government Printing Office, Washington, D.C. 1951.
28. *A Mid-Century Look at Resources*. Brookings Institution, Washington, D.C. 1953. Mimeo.
29. *Resources for Freedom*. U.S. President's Materials Policy Commission—Paley Report, U.S. Government Printing Office, Washington, D.C. 1952.

30. *Highway Statistics (Annual)*. Bureau of Public Roads, U.S. Department of Commerce, U.S. Government Printing Office, Washington, D.C.
31. *Automobile Facts and Figures (Annual)*. Automobile Manufacturers Association, Detroit, Michigan.
32. *Accident Facts (Annual)*. National Safety Council, Chicago, Illinois.
33. *Annual World Motor Census*. McGraw-Hill International Corporation.
34. Harper, S. F. *Ten Years of State Highway Revenues*. The Tax Digest. May 1951.
35. *A Ten-Year National Highway Program*. A Report to the President. The President's Advisory Committee on a National Highway Program. January 1955. U.S. Government Printing Office, Washington, D.C.
36. *Selected References on Trends and Forecasts for Estimating Highway Requirements*. Memo 3, Circular 263, Highway Research Board, Washington, D.C. 1955.
37. *Some Aspects of the Rapid-Transit Situation*, Technical Memorandum B-19, Institute of Transportation and Traffic Engineering. Berkeley, California. November 1953.
38. *Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program*. House Document No. 139, 84th Congress, 1st Session. U.S. Government Printing Office, Washington, D.C. 1955.

CHAPTER SIX

THE CRITICAL HOUR

Traffic estimation procedures usually deal with daily volumes. These may be average annual daily or average week-day volumes. Daily volumes are useful in economic analyses such as benefit-cost or earnings-cost studies. Since the average annual daily volume is exceeded by an average of 160 days a year, *the significant volume for design and operation is that using the facility during the "critical hour."*

The critical hour is the hour in a year whose traffic volume is of such magnitude that it out-ranks all reasonable or ordinary volumes but is *outranked* by a few extraordinary volumes occurring during special occasions. Designs based on the critical hour volume will usually handle about ninety-seven or ninety-eight percent of the traffic requirements.

If design were based on the highest hour-volume, the capacity requirements might be one and one-half times that of the critical hour, and yet the facility would be used at full capacity only once a year. It has been found for rural areas that an hour at or near the thirtieth highest is adequate,¹ and the thirtieth hour may likewise serve in the urban area.

Each urban area and each land use within the urban area has its own distinctive traffic pattern, and the critical hour should be determined for its own locality. Expensive highway facilities are worthy of better than rule-of-thumb methods, and justify better than second-hand patterns imported from other localities.

To find the critical hour for urban areas, rank all of the hours of the year by traffic volume and plot on graph paper, letting the Y axis represent hours and the X axis, volumes. The breaking point of the curve (the point where the rate of change of direction is the greatest) will give the critical hour. This point may appear on the curve at or near the thirtieth highest hour. In case there is

¹ Highway Capacity Manual, Highway Research Board and Bureau of Public Roads. Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. 1950.

Table VI-1

VARIATIONS IN TRAFFIC FLOW ON MAJOR URBAN FACILITIES DURING 1 YEAR

City and location	Type ¹ of facility	24-hour volume			Percentage of average 24-hour volume in certain hourly volumes during year				
		Average for year	Percentage of average in—		Maximum hour	Tenth highest hour	Twentytieth highest hour	Thirtieth highest hour	Fiftieth highest hour
			Maximum 24 hours	Tenth highest 24 hours					
Birmingham, Ala.: Roebuck Blvd.	A-O	6,742	155.9	143.7	17.2	15.5	14.7	13.8	9.9
Chicago, Ill.:									
Leif Erikson Dr.	E-I	41,590	137.9	129.0	12.6	11.2	10.7	10.4	10.1
Michigan Ave.	A-D	69,736	131.9	118.2	10.0	8.9	8.3	8.2	7.9
Monroe St.	A-D	32,102	140.0	124.1	11.5	9.6	9.2	8.9	8.6
Ashland Blvd.	A-I	16,919	129.0	114.6	10.4	9.9	9.6	9.5	9.3
Jackson Blvd.	A-I	20,939	133.3	122.1	11.3	10.2	9.8	9.6	9.4
Sacramento Blvd.	A-I	13,243	142.5	122.5	13.5	12.3	11.9	11.8	11.5
Warren and Washington Blvds.	A-I	39,374	138.4	123.8	12.9	12.1	11.3	10.3	9.9
Lake Shore Dr.	E-I	85,698	140.7	124.6	13.5	11.5	10.9	10.7	10.3
Detroit, Mich.:									
Joy Rd.	I	10,784	139.6	129.9	15.2	11.8	11.3	11.1	10.6
Six Mile Rd.		22,768	124.5	117.3	11.1	9.8	9.8	9.7	9.4
14th St. at Edison		12,894	140.6	122.6	15.3	12.4	12.0	11.8	11.7
Albuquerque, N. Mex.: North 4th St.	A-O	3,375	173.7	146.2	15.2	13.7	13.2	12.8	12.4
Santa Fe, N. Mex.: Don Gaspar St.	A-D	4,679	166.1	133.7	18.6	12.6	12.1	11.8	11.3
New York, N. Y.: George Washington Bridge	E-O	22,000	245.6	212.4	22.5	18.8	17.8	16.9	11.6
Philadelphia, Pa.:									
Chestnut St. Bridge ²	E-D	30,200	129.7	120.1	8.7	8.1	8.0	7.3	6.9
Parkway and 22d St.	A-D	51,200	113.6	112.4	11.5	11.4	11.1	11.0	10.8
Spring Garden Bridge	A-I	19,500	122.5	118.2	16.6	12.7	12.4	11.7	11.0
Girard Ave. Bridge	A-I	43,800	120.2	117.1	11.1	10.6	10.2	10.0	9.8
Wissahickon and Ridge Sts.	A-O	40,500	119.1	114.0	11.9	10.4	10.1	9.6	9.4
City Line Bridge	E-O	24,360	148.4	138.7	13.1	11.7	11.4	10.7	10.2
Allegheny and Hunting Park	A-O	29,500	129.9	118.8	10.6	10.1	10.0	9.7	9.4
Broad, Glenwood, Cambria	A-I	51,000	122.3	118.8	9.3	9.2	9.0	8.8	8.6
5th and Roosevelt Blvd.	A-O	23,400	151.1	145.4	16.6	14.3	13.6	13.6	13.3
Ogontz and Olney Ave.	A-O	19,670	124.2	120.9	12.9	10.7	10.5	10.3	10.1
Washington, D. C.:									
Fourteenth St. Bridge	A-I	41,300	138.5	115.7	9.6	9.2	9.0	8.8	8.2
Memorial Bridge	E-I	36,700	151.8	116.9	14.7	13.0	12.4	12.1	11.9
Key Bridge	A-I	32,600	143.0	117.6	11.3	9.7	9.7	9.4	8.8
Anacostia Bridge	A-O	32,278	114.0	104.4	9.0	8.3	8.1	7.9	7.3
Benning Rd. NE	A-O	27,725	141.6	115.6	12.8	9.1	8.7	8.5	7.5
Bladensburg Rd. NE	A-O	27,123	138.6	107.9	10.4	9.7	9.1	9.0	8.5
Connecticut Ave.	A-I	26,842	116.7	110.0	9.1	8.8	8.5	8.0	7.2
Pennsylvania Ave.	A-I	24,388	123.1	112.4	8.8	8.3	7.9	7.7	6.6
Georgia Ave. NW	A-O	21,628	125.7	117.1	10.4	9.1	8.7	8.7	8.1
Wisconsin Ave.	A-O	20,786	129.4	111.8	10.4	10.2	9.7	9.5	9.2
Rhode Island Ave. NW	A-I	19,695	117.6	103.8	9.3	8.8	8.5	8.3	7.9
13th St. NW	C-D	16,857	121.7	106.9	10.6	9.6	9.4	9.1	8.1
K St. NW	A-D	15,618	115.2	109.1	10.7	10.4	10.0	9.9	8.9
Total		28,329	136.8	122.6	12.4	10.9	10.5	10.2	9.5

¹ Type of facility code:

E = Expressway.

A = Arterial.

C = City Street.

O = Outlying.

I = Intermediate.

D = Downtown.

² One-way.SOURCE: Table 25, *Highway Capacity Manual*, 1950.

no distinctive breaking point an arbitrary choice of hour must be made.

Discretion is required in the acceptance of critical hour values. A distinctive traffic pattern is developed by various urban areas and land uses. Whereas the thirtieth highest hour value averages about fifteen percent of the annual average daily traffic for the rural area it is found that this value may progressively decrease as traffic penetrates the suburban area, then the intermediate area and finally the downtown area, where the value may be only half that of the rural area. A number of factors are responsible for this, among which are differences of travel habits between rural and urban residents, and the effect of congestion in restricting travel and in spreading the peak over a longer period of time.

For example, street capacity might be so low and the potential so high that an even flow of traffic resulted during the entire twenty-four hours. The critical hour (any one of the twenty-four) would have a value of 4.17 percent of the daily traffic. If such were the case the arteries would be utilized all day to their possible capacity. If the value of 4.17 percent were used as the critical hour design value it would only perpetuate the prevailing inadequacy.

Therefore, a check should be made to determine the magnitude and duration of congestion. Since design should be for practical capacity, the design hour should reflect conditions at practical capacity if the resultant design is to provide a free flowing facility. A factor of potential demand may be determined by finding the thirtieth highest hour value for streets in the area which are used to practical capacity during that hour. An average value of ten to twelve percent is indicated from the few studies made to date. Whatever value is used, the critical hour figure must be weighed again in light of traffic growth.

The cordon count around the CBD does not grow in direct proportion to the growth of the city, for as the city grows in population it expands space-wise to the extent that trips from the outer zones to the CBD are not made with the frequency of those from the inner zones. Some of this reduced growth is due to congestion but the factor of distance is equally important. It was found in

Detroit, for example, that at a distance of ten miles from the CBD, one person in three did not visit the CBD as often as once a year.

Another check should be made before adopting a critical hour value to be used in design. After estimating the cordon count for a future date, the capacities of all facilities cutting the cordon (including the proposed facilities) should be computed to see how the total capacity will compare with the total estimated volume.

Not only is there a distinctive traffic pattern resulting from the land uses, but there is also one for the several highway types—freeway, boulevard and city street. If possible the pattern for land uses and highway types should be ascertained.

With the critical hour values decided, some consideration should be given to kinds of movements found. While the straight-line movement is identified with rural areas, two movements are identifiable in urban areas—the straight line and the circulatory. Although they overlap to some extent the dominant movement at the periphery of the city is the straight line flow.

This extends inwardly as the dominant type until the CBD is reached. The dominant flow at the CBD may be circulatory. This flow characteristic explains to some degree why a seven and one-half percent or lower critical hour value may be found at the CBD. The accumulation of vehicles from all sources at the CBD, in parking accommodations and in moving lanes, furnishes a great reservoir to provide a heavy movement of traffic extending over a long period of time.

The critical hour (or design hour) percentages are applied to the classified average annual daily volume (or comparative percentages are applied to the average week-day volumes) assigned to the several elements of the system. A tabulation by types of vehicle results.

The design volumes are further translated into directional flows by applying percentage factors representing the dominant and subdominant flows. The dominant flow is commonly assumed to be about sixty percent of the design hour flow, moving towards employment and sales centers in the morning and reversing itself toward residential areas in the afternoon. There-

Table VI-2

COMPARISON OF VARIATIONS IN TOTAL TRAFFIC FLOW WITH VARIATIONS IN ONE DIRECTION OF TRAVEL

State	Recorder station No.	Route No.	Year starting	24-hour volume			Percentage of average 24-hour volume in certain hourly volumes during year					
				Average for year	Percentage of average in—		Maximum hour	Tenth highest hour	Twentieth highest hour	Thirtieth highest hour	Fiftieth highest hour	
					Maximum 24 hours	Tenth 24 hours						
BOTH DIRECTIONS COMBINED:				Vehicles	Percent	Percent	Percent	Percent	Percent	Percent	Percent	
	New Jersey (Essex County)	NB and SB	25	Jan. 1, 1941	62,250	143.6	131.6	11.2	9.6	9.3	9.3	8.8
	New Jersey (Edison Bridge)	NB and SB	35	do	25,381	284.3	231.6	24.0	19.1	17.3	16.2	15.4
	New Jersey (Woodbridge)	NB and SB	35	do	22,052	229.2	211.5	26.8	18.0	17.0	15.9	13.6
	Connecticut	6 and 7	1	Mar. 31, 1939	13,624	292.5	227.9	25.7	21.2	19.2	18.6	17.7
	Delaware	C	13	June 8, 1941	6,741	254.2	206.5	23.8	20.5	20.0	19.1	16.9
	Wisconsin	2 and 3	¹ 41	Jan. 8, 1938	5,674	305.9	220.2	29.1	22.2	18.9	18.1	16.3
ONE DIRECTION:												
	New Jersey (Essex County)	SB	25	Jan. 1, 1941	30,150	159.9	137.8	13.3	11.4	11.1	10.9	10.3
	New Jersey (Edison Bridge)	SB	35	do	11,656	436.3	315.3	36.0	28.0	24.7	24.7	23.6
	New Jersey (Woodbridge)	SB	35	do	10,766	489.0	255.3	41.5	30.1	26.2	21.7	18.9
	Connecticut	6-WB	² 1	Mar. 31, 1939	6,813	287.7	244.3	29.7	25.6	24.0	23.4	22.0
	Delaware	C-NB	13	June 8, 1941	3,371	344.9	235.9	40.1	34.6	31.4	29.2	25.6
	Wisconsin	2-WB	¹ 41	Jan. 8, 1938	2,817	405.6	241.8	43.7	30.7	25.6	22.9	20.2

¹ U. S. numbered routes. Others are State routes.² Merritt Parkway.SOURCE: Table 26, *Highway Capacity Manual*, 1950.

fore, lanes should be provided for the dominant flows in *both* directions.

Unless reversible lanes are provided the total number of lanes in the expressway design should be sufficient to take care of about 60 percent of the design hour volume in each direction. In the core of the city, there is a close balance in direction of flow. The actual values of dominant and sub-dominant flows should be determined for each locality by field counts on existing facilities. Although rural areas do not usually show the high imbalance of suburban and urban areas, there is some, and in roads serving recreational areas it may exceed that of the urban area.

As an example, suppose an AADT of 50,000 is estimated. A critical hour of ten percent is adopted, and a dominant flow of sixty percent is found. Lane capacity of 1000 vehicles per hour is assumed. Trucks are estimated at twenty percent of total.

Design hour volume: 10% of 50,000 = 5,000

Dominant flow: 60% of 5,000 = 3,000

Sub-dominant flow: 40% of 5,000 = 2,000

Classification by type: 2,400 autos, 600 trucks
in dominant flow

Lanes required: 3 for dominant flow

2 for sub-dominant flow

Five lanes with a reversible middle lane would meet minimum requirements. A better design would be a six-lane divided highway.

Cordon counts around the CBD, at the periphery of the urban area, and at an intermediate cordon, should provide information for determining critical hour and directional flow values.

SELECTED REFERENCES FOR SUPPLEMENTAL READING

1. Highway Capacity Manual. Highway Research Board and Bureau of Public Roads. United States Government Printing Office, Washington 25, D. C. 1950.
2. Traffic Engineering Handbook, 1950, Institute of Traffic Engineers, Washington, D. C.
3. Traffic Engineers Technical Notebook, Institute of Traffic Engineers, Washington, D. C. 1952.
4. Carroll, J. D., Jr. *Memorandum on Design Capacity Standards for Roadways in the Detroit Metropolitan Area*. Detroit Metropolitan Area Traffic Study, Detroit, Michigan, November 1954.
5. *A Policy on Geometric Design of Rural Highways*. American Association of State Highway Officials, Washington, D. C. 1954.

APPENDIX A

TRAFFIC DATA: FREEWAYS, TOLL ROADS, AND BRIDGES

I. FREEWAYS: Diverted and Induced Traffic on Limited-Access Free Highways

EFFECT OF HOLLYWOOD FREEWAY ON PARALLEL ROUTES

(16-hour July Monday Counts)

NO CO	Distance from freeway, miles	On Santa Monica Blvd. W. of Sunset	On Sunset Blvd. (Rt. 2)		On Olympic (Rt. 173) W. of Figueroa	On San Fernando (Rt. 4) N.W. of Ave. 26	On Slauson Ave.		On Manchester Ave. (Rt. 174)	
			W. of Sta. Mon.	E. of Sta. Mon.		W. of Figueroa	E. of Figueroa	W. of Figueroa	E. of Figueroa	
		1.1	1.1	1.1	1.5	2.1	6.1	6.1	8.1	8.1
	1947	9,204	22,086	30,555	No count	No count	No count	No count	30,859	30,044
	1948	9,414	21,464	31,155	33,025	No count	25,807	25,471	31,675	31,727
	1949	9,263	21,768	30,314	34,163	29,677	26,728	27,481	29,196	30,346
	1950	9,662	21,877	31,515	37,265	32,077	29,085	29,790	30,220	32,786
	Hollywood Freeway opened								Stage 1	
	1951	7,563	19,973	27,579	36,742	32,409	26,533	28,015	28,349	29,483
									Stages 2 and 3	
	1952	5,634	12,119	16,661	34,087	31,902	27,552	27,807	28,636	29,506
	1953	5,690	10,316	15,299	31,713	32,463	27,779	27,683	28,489	30,052

SOURCE: California Highways and Public Works, September, 1953.

TRAFFIC TRENDS ON SHIRLEY HIGHWAY (ROUTE 350) AND ROUTE U.S. 1, VIRGINIA

Screen Line 1

LOCATION Int. Routes U.S. 1 North, U.S. 1 South and 241 North Fairfax County				LOCATION Int. Routes 350 North, 350 South—1 Mile South of Route 236 Fairfax County				
Route U.S. 1 (South Leg)				Route 350 (South Leg) (Shirley Highway)				
Year	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total
(24-Hour Traffic)				(24-Hour Traffic)				
1945	4,135	2,272	1,880	8,287				
1946	5,449	4,535	2,192	12,176				
1947	6,769	3,908	2,615	13,292				
1948	7,865	4,002	2,990	14,857				
*1949	4,123	1,743	1,886	7,752				
1950	8,123	2,763	3,521	14,407	3,607	2,789	535	6,931
1951	8,757	3,173	4,280	16,210	4,332	3,682	468	8,482
1952	10,192	4,149	2,793	17,134	5,273	4,784	3,093	13,150
1953	11,172	4,363	2,582	18,117	6,470	5,409	3,598	15,477
1954	11,481	4,205	2,404	18,090	7,859	5,810	3,603	17,272

* This count appears abnormally low.

Route U.S. 1 (North Leg)				Route 350 (North Leg) (Shirley Highway)				
Year	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total
(24-Hour Traffic)				(24-Hour Traffic)				
1945	3,574	2,094	1,713	7,381				
1946	4,791	4,252	1,905	10,948				
1947	6,107	3,614	2,392	12,113				
1948	6,968	3,792	2,793	13,553				
1949	4,727	2,004	1,881	8,612				
1950	6,693	2,553	3,328	12,574	3,607	2,789	535	6,931
1951	7,021	2,714	3,970	13,705	4,332	3,682	468	8,482
1952	7,802	3,604	2,217	13,623	5,273	4,784	3,093	13,150
1953	8,706	3,864	1,987	14,557	6,470	5,409	3,598	15,477
1954	8,289	3,490	1,626	13,405	7,859	5,810	3,603	17,272

Route 350 opened to pleasure-type traffic September 6, 1949.

Route 350 opened to commercial-type traffic May 31, 1951.

Screen Line 2

LOCATION Int. Routes U.S. 1 North, U.S. 1 South and 235 East Fairfax County				LOCATION Int. Routes 350 North, 350 South and 617 East Fairfax County				
Route U.S. 1 (South Leg)				Route 350 (South Leg) (Shirley Highway)				
Year	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total
(24-Hour Traffic)				(24-Hour Traffic)				
1945	2,934	3,171	1,322	7,427				
1946	3,897	5,539	1,550	10,986				
1947	5,340	5,890	2,568	13,798				
1948	5,132	4,866	2,021	12,019				
1949	4,771	4,827	1,208	10,806				
1950	5,751	3,617	2,692	12,060	2,133	2,142	134	4,409
1951	6,298	3,885	3,031	13,214	2,601	2,752	319	5,672
1952	7,807	5,250	1,517	14,574	2,387	2,608	2,053	7,048
1953	6,998	4,759	1,333	13,090	3,288	3,312	2,499	9,099
1954	6,778	4,577	1,001	12,356	3,526	3,350	2,652	9,528

Route U.S. 1 (North Leg)				Route 350 (North Leg) (Shirley Highway)				
Year	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total	Virginia Passenger Cars	Foreign Passenger Cars	Commercial Vehicles	Total
(24-Hour Traffic)				(24-Hour Traffic)				
1945	2,714	3,006	1,322	7,042				
1946	3,671	5,171	1,550	10,392				
1947	5,220	5,560	2,573	13,353				
1948	4,758	4,516	2,030	11,304				
1949	4,511	4,446	1,164	10,121				
1950	5,340	3,234	2,698	11,272	2,621	2,430	149	5,200
1951	5,738	3,429	3,038	12,205	3,025	3,276	307	6,608
1952	7,063	4,729	1,428	13,220	3,182	3,376	2,095	8,653
1953	6,279	4,166	1,293	11,738	4,334	4,238	2,637	11,209
1954	6,088	3,896	939	10,923	4,738	4,186	2,761	11,685

Route 350 opened to pleasure-type traffic September 6, 1949.

Route 350 opened to commercial-type traffic May 31, 1951.

SOURCE: Virginia Department of Highways.

**VEHICULAR TRAFFIC ON THE COLUMBIA RIVER HIGHWAY, U. S. 30
AND THE CROWN POINT HIGHWAY, OREGON**

AVERAGE DAILY TRAFFIC

<i>Year</i>	<i>Location "B" Crown Point Highway 2.6 Miles East of Troutdale</i>	<i>Location "A" Columbia River Highway, U. S. 30 on Sandy River Bridge (Controlled Access)</i>	<i>Combined Total</i>
1937	2,600		
1938	2,600		
1939	2,500		
1940	2,500		
1941	2,600		
1942	1,900		
1943	1,300		
1944	1,200		
1945	2,300		
1946	2,700		
1947	3,100		
1948	3,000		
1949	Water Grade Route Completed		
1950	1,400	3,500	4,900
1951	1,500	3,900	5,400
1952	1,500	4,200	5,700
1953	1,500	4,800	6,300
	Length on Crown Point Highway		23.30 miles
	Length on Columbia River Highway, U. S. 30		18.02 miles
		Savings	5.28 miles

SOURCE: Oregon State Highway Department.

**ANNUAL AVERAGE DAILY TRAFFIC VOLUMES ON HIGHWAYS
BETWEEN HOUSTON AND GALVESTON**

<i>Year</i>	<i>U. S. 75¹</i>	<i>S. H. 3² U. S. 75</i>	<i>S. H. 146</i>	<i>S. H. 6</i>	<i>All Routes</i>
1947		4,230	690	3,270	8,190
1948		5,320	2,240	3,270	10,830
1949		6,300	2,350	3,850	12,500
1950		6,330	2,850	4,400	13,580
1951		6,930	3,040	3,870	13,840
1952	7,760	2,490	3,290	2,900	16,440
1953	9,490	2,650	3,490	3,440	19,070

¹ Gulf Freeway (New Route U. S. 75). Opened to traffic August 1952.

² Changed from U. S. 75 to S. H. 3 when Gulf Freeway opened to traffic.

SOURCE: Texas Highway Planning Survey.

**ANNUAL AVERAGE DAILY TRAFFIC VOLUMES ON HIGHWAYS
BETWEEN DALLAS AND FT. WORTH**

(U.S. 80 and S.H. 183 between Dallas and Ft. Worth)

<u>Year</u>	<u>U.S. 80 A.T.R. #1</u>	<u>S.H. 183 S.P.R. #55</u>	<u>Total Both Routes</u>
1938	8,340		
1939	9,102		
1940	9,565		
1941	11,122		
1942	9,221		
1943	7,698		
1944	8,081	1,458 ¹	9,539
1945	7,963	2,183	10,146
1946	10,746	3,555	14,301
1947	11,118	4,412	15,530
1948	11,671	4,900	16,571
1949	12,998	5,641	18,639
1950	14,424	6,859	21,283
1951	15,509	7,710	23,219
1952	16,407	8,666	25,073
1953	18,171	10,250	28,421

¹ S.H. 183—opened to traffic October 1944.

SOURCE: Texas Highway Planning Survey.

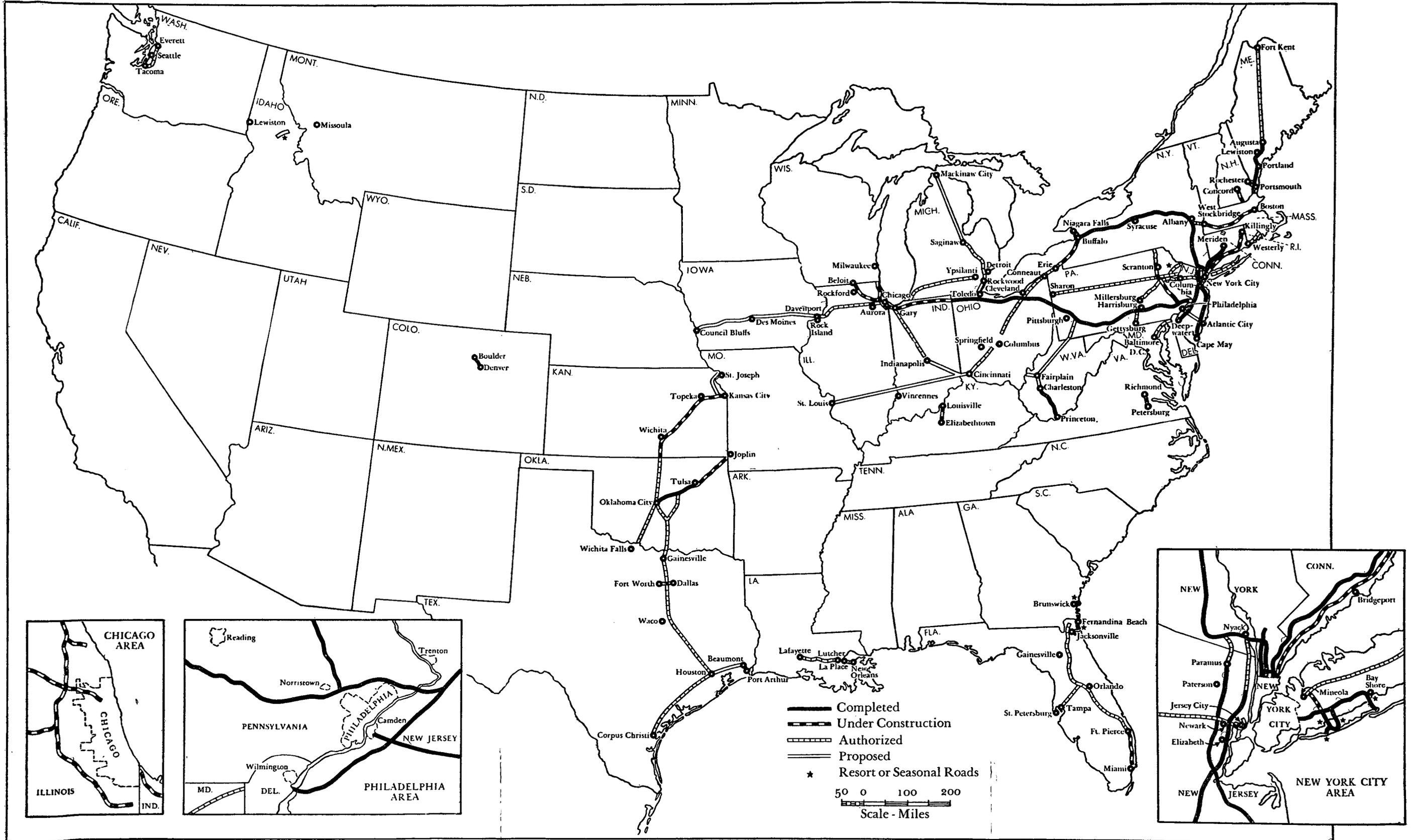
**ANNUAL AVERAGE DAILY TRAFFIC VOLUMES ON U.S. 67
ROCKWALL COUNTY, TEXAS
BEFORE AND AFTER A NEW ROUTE WAS OPENED**

<u>Year</u>	<u>U.S. 67</u>	<u>U.S. 67 (New Location)</u>	<u>Total Both Routes</u>
1946	3,640		
1947	3,720		
1948	3,940		
1949	3,740		
1950	3,990		
	<i>F.M. 7¹</i>		
1951	1,960	2,940	4,900
1952	2,160	3,310	5,470
1953	1,930	4,130	6,060

¹ Old Route U.S. 67 changed to F.M. 7.

SOURCE: Texas Highway Planning Survey.

TOLL ROADS IN THE UNITED STATES; EXISTING AND PROPOSED



PHYSICAL CHARACTERISTICS AND CAPITALIZED COSTS OF MAJOR TOLL ROADS COMPLETED AND IN OPERATION

	Colorado Turnpike ¹	Maine Turnpike	New Hampshire Turnpike ¹	New Jersey Turnpike	Oklahoma Turnpike	Pennsylvania Turnpike		
						Original Section	Eastern Extension	Western Extension
<i>Physical Characteristics²</i>								
Length in miles	17.3	47.2	14.7	117.6	88.0	158.9	100.9	67.4
Number of lanes	4	4	4	4 and 6	4	4	4	4
Width of lanes	12'	12'	12'	12'	12'	12'	12'	12'
Minimum width of median	20'	26'	24'	20'	15'	10'	10'	10'
Width of outside shoulder	10'	10'	10'	10'	12'	10'	10'	10'
Minimum width of R/W	200'	300'	200'	300'	200'	200'	200'	200'
Number of interchanges (incl. termini)	1	6	1	17	6	10	8	6
Number of structures	23	43	18	263	78	156	126	98
Type of surface	PCC	BC	BC	BC	BC	PCC	PCC	PCC
Maximum ascending grade	5%	4%	3%	3%	3%	3%	3%	3%
Minimum radius of curves	—	5,730'	5,730'	3,000'	11,460'	955'	955'	955'
Year completed	1952	1947	1950	1952	1953	1940	1950	1951
<i>Capitalized Costs (000 omitted)³</i>								
A. Right-of-way	\$ 554	\$ 697	\$ 553	\$ 22,115	\$ 1,382	\$ 3,993	\$ 5,100	\$ 4,040
B. Engineering	484	987	450	17,700	2,192	4,474	5,500	4,850
C. Construction	4,996	16,916	5,767	231,695	31,608	53,537	64,400	61,610
1) Major bridges				26,739				
2) Other structures	(926)	(4,880)	(1,113)	57,346	(7,771)	(22,482)		
3) Roadway costs	3,975	11,103	4,460	125,686	22,580	29,596	56,958	54,398
a) Paving	1,997	4,689	1,703	44,958	9,791	14,156		
b) Grading	1,866	6,414	2,658	53,125	11,057	14,336		
c) Utility relocation	12	—	99	8,465	515	376		(1,400)
d) Other	100	—	—	19,138	1,217	728		
4) Buildings, service facilities, and toll equipment	88	757	34	16,634	400	911		
5) Other equipment, suppl., and adm.	7	176	160	3,045	857	548	1,800	800
6) Contingencies	—	—	—	2,245	—	—	5,642	6,412
Subtotal, R/W, Engr., and Constr.	6,034	18,600	6,770	271,510	35,182	62,004	75,000	70,500
D. Financing costs								
1) Interest during constr.	279	1,003	—	6,836	3,131	2,955	8,483	4,963
2) Bond discounts	—	997	—	647	245	2,918	2,948	1,550
3) Redemption call premiums	—	—	—	—	—	3,495	—	—
4) Financial fees, and other bond adm.	53	—	—	5,959	27	5,792	569	487
Subtotal, financing costs	332	2,000	—	13,442	3,403	15,160	12,000	7,000
E. Total Capitalized Costs	6,366	20,600	6,770	284,952	38,585	77,164	87,000	77,500
F. Cost per mile (excluding D)	368	394	461	2,309	400	390	743	1,046
G. Cost per mile (adj. to 1/1/54 prices)	356	532	605	2,235	400	872	976	1,140

PHYSICAL CHARACTERISTICS AND CAPITALIZED COSTS OF MAJOR TOLL ROADS UNDER CONSTRUCTION

	Conn. Greenwich-Killingly Expressway ¹	Indiana Turnpike	Kentucky Turnpike ²	Maine Turnpike Extension	Mass. Turnpike	New Jersey Garden State Parkway ¹	New York Thruway Basic Section	Ohio Turnpike	Pennsylvania Turnpike		
									Delaware River Extension	North-eastern Extension	West Va. Turnpike
<i>Physical Characteristics²</i>											
Length in miles	129.0	156.0	40.0	66.0	123.3	147.5 ⁴	427.0	241.4	32.3	110.0	87.6
Number of lanes	2 and 4	4	4	4	4 and 6	4 and 6	4 and 6	4	4	4	2
Width of lanes	12'	12'	12'	12'	12'	12'	12 and 13'	12'	12'	12'	12'
Minimum width of median	—	20'	20'	26'	14'	50'	20'	56'	10'	10'	None
Width of shoulder	10'	10'	10'	8'	10'	10'	9'	10'	13'	10'	9'
Minimum width of R/W	180'	104'	300'	300'	300'	200'	200'	200'	200'	200'	—
Number of interchanges (incl. termini)	100	11	7	7	14	64	53	15	6	8	6
Number of structures	283	253	28	90	185	371	504	368	128	369	74
Type of surface	PCC	PCC	PCC	BC	BC	BC	PCC	PCC	PCC	PCC	PCC
Maximum ascending grade	4%	2%	3%	5%	3½%	3%	3%	2%	3%	3%	—
Minimum radius of curves	1,900'	—	1,900'	—	3,000'	—	2,800'	—	—	—	1,000'
<i>Capitalized Costs (000 omitted)³</i>											
A. Right-of-way	\$ 61,426	\$ 9,556	\$ 2,550	\$ 1,800	\$ 10,960	\$ 41,000	\$ 45,112	\$ 11,223	\$ 8,500	\$ 9,650	\$ 8,200
B. Engineering	19,708	16,809	2,650	2,600	12,609	19,500	36,949	19,489	4,060	15,315	8,555
C. Construction	264,837	213,635	29,456	42,020	183,431	200,302	450,628	252,644	45,440	171,335	94,745
1) Major bridges	43,274	—	1,765	1,580	10,865						9,746
2) Other structures	70,551	(55,849)	3,085	7,684	35,773			(74,846)			15,513
3) Roadway costs	107,450	107,671	20,135	24,421	103,386			141,560	39,490	149,821	62,258
a) Paving	32,326	39,375	7,900	10,406	25,807			59,287			8,758
b) Grading	63,910	56,188	10,400	12,660	63,737			66,003			44,799
c) Utility relocation	4,594	3,960	250	100	4,689			(6,348)	2,220	(1,600)	2,200
d) Lighting, signs, rail, and miscellaneous	6,620	8,148	1,585	1,255	9,153			(26)	14,050		6,501
4) Buildings, service facilities, and toll equipment	15,107	16,580	965	3,315	6,366			(4,789)	6,277		2,858
5) Other equipment, suppl., and adm.	—	3,364	300	900	2,000	(7,000)	(1,417)	4,201	650	1,840	1,370
6) Contingencies	28,455	30,171	3,206	4,120	25,041	(12,802)		25,760	5,300	19,674	3,000
Subtotal, R/W, Engr., and Constr.	345,971	240,000	34,656	46,420	207,000	260,802	532,689	283,356	58,000	196,300	111,500
D. Financing costs											
1) Interest during constr.	—	33,700	3,209	5,580	25,006	21,840	2,970	33,914	5,200	16,457	15,331
2) Bond discounts	—	6,300	635	3,000	5,378	2,358	—	7,824	1,300	4,660	6,419
3) Redemption call premiums	—	—	—	—	—	—	—	—	—	—	—
4) Financial fees, and other adm.	—	—	—	—	1,616	—	—	906	500	463	—
Subtotal, financing costs	52,029	40,000	3,844	8,580	32,000	24,198	2,970	42,644	7,000	21,580	21,750
E. Total Capitalized Costs	398,000	280,000	38,500	55,000	239,000	285,000 ⁴	535,659	326,000	65,000	217,880	133,250
F. Cost per mile (excluding D)	2,682	1,538	866	703	1,683	1,578	1,248	1,174	1,796	1,785	1,273

¹ The Colorado Turnpike, Kentucky Turnpike, New Hampshire Turnpike, and Connecticut Expressway are constructed and operated by the State highway departments. The Garden State Parkway is being constructed by the New Jersey Highway Authority, an agency created within the Highway Department. All other facilities are under separate authorities.

² The Connecticut Expressway and the New Jersey Garden State Parkway are barrier type facilities, and permit free access between toll barriers. The N. Y. Thruway is partially a barrier-type facility.

³ Includes all costs financed from sale of bonds.

⁴ Excludes 17.5 miles built by State Highway Department, and the cost thereof.

II. TOLL ROADS: Diverted and Induced Traffic on Toll Roads

INDUCED TRAFFIC ON TOLL ROADS

<i>Highway Location</i>	<i>Percent of Induced Traffic Over Trend by Years</i>				
	<i>First</i>	<i>Second</i>	<i>Third</i>	<i>Fourth</i>	<i>Fifth</i>
Penn. Turnpike, Eastern Extension	—	23	32		
Denver-Boulder Turnpike	14	19			
Merritt Parkway (Conn.)	28	26	24	25	
Wilbur Cross Parkway (Conn.)	23	20			
Maine Turnpike	11	19	25	28	31
New Jersey Turnpike	14				
Turner Turnpike (Okla.)	44				
AVERAGE	22	21	27	26	31

SOURCE: Bureau of Public Roads, 1954.

PENNSYLVANIA TURNPIKE, EASTERN EXTENSION — PHILADELPHIA CORDON

	<i>U.S. 422</i>	<i>U.S. 30</i>	<i>Total</i>
Counts, June-Aug. 1950	10,653	10,648	21,301

Turnpike opened November 20, 1950

Traffic at 4 counters (#8, 10, 21, and 22) in eastern Pennsylvania increased at average rate of 4 percent per year (1949 to 1950).

<i>Expected</i>	<i>Average on Turnpike</i>
June-Aug. 1951 = 21,301 × 1.04 = 22,150	Unknown
1952 = 22,150 × 1.04 = 23,000	9,041
1953 = 23,000 × 1.04 = 23,920	9,002

Traffic Counts

	<i>Turnpike</i>	<i>U.S. 422</i> <i>U.S. 30</i>	<i>Total</i>	<i>Percent Induction in Corridor</i>
June-Aug. 1952	9,041	19,729	28,770	$\frac{28,770}{23,000} = 25\%$
June-Aug. 1953	9,002	22,918	31,920	$\frac{31,920}{23,920} = 34\%$

PENNSYLVANIA TURNPIKE, EASTERN EXTENSION—HARRISBURG CORDON

	<u>U. S. 422</u>	<u>U. S. 230</u>	<u>Total</u>
Counts, June–Aug. 1950	12,959	7,882	20,841

Turnpike opened November 20, 1950

Traffic at 4 counters (#8, 10, 21, and 22) in eastern Pennsylvania increased at average rate of 4 percent per year (1949 to 1950).

<i>Expected</i>	<i>Average on Turnpike</i>
June–Aug. 1951 = 20,841 × 1.04 = 21,650	Unknown
1952 = 21,650 × 1.04 = 22,550	11,423
1953 = 22,550 × 1.04 = 23,400	13,669

	<u>Traffic Counts</u>			<u>Percent Induction in Corridor</u>
	<u>Turnpike</u>	<u>U. S. 422 U. S. 230</u>	<u>Total</u>	
June–Aug. 1952	11,423	16,060	27,483	$\frac{27,483}{22,550} = 22\%$
June–Aug. 1953	13,669	16,790	30,459	$\frac{30,459}{23,400} = 30\%$

DENVER-BOULDER TURNPIKE, COLORADO

Traffic Counter #1 (North of Lafayette)

A.D.T.—1949 = 5,754	
—1950 = 6,134	
—1951 = 5,524 (Do not know reason for drop, so assumed (6,530) 1951 to increase 6.6 percent over 1950)	

Turnpike opened January 21, 1952

Traffic increased 6.6 percent from 1949 to 1950.

<i>Expected</i>	<u>Traffic Counts</u>			<i>Average on Total Length of Turnpike</i>
	<u>Turnpike</u>	<u>Counter #1</u>	<u>Total</u>	<u>Percent Induction in Corridor</u>
A.D.T.—1952 6,530 × 106.6 = 6,950				3,905
—1953 6,950 × 106.6 = 7,410				4,596
A.D.T.—1952	3,905	4,041	7,946	$\frac{7,946}{6,950} = 14\%$
—1953	4,596	4,196	8,792	$\frac{8,792}{7,410} = 19\%$

MAINE TURNPIKE, KENNEBUNK-BIDDEFORD SECTION (U.S. 1)

1947 A.A.D.T. 6,406

Turnpike opened December 13, 1947

Traffic Trend in Maine:

1947-48 = +8.0% 1948-49 = +5.7% 1949-50 = +6.1%
 1950-51 = +5.9% 1951-52 = +5.1% 1952-53 = +4.6%

Expected

1948 = 6,406 × 1.080 = 6,900
 1949 = 6,900 × 1.057 = 7,300
 1950 = 7,300 × 1.061 = 7,750
 1951 = 7,750 × 1.059 = 8,200
 1952 = 8,200 × 1.051 = 8,620

A.A.D.T. on Turnpike

3,416
 3,902
 4,356
 4,871
 5,234

	Traffic Counts			Percent Induction in Corridor
	Turnpike	U.S. 1	Total	
1948	3,416	4,194	7,610	$\frac{7,610}{6,900} = 11\%$
1949	3,902	4,774	8,676	$\frac{8,676}{7,300} = 19\%$
1950	4,356	5,211	9,567	$\frac{9,567}{7,750} = 25\%$
1951	4,871	5,551	10,422	$\frac{10,422}{8,200} = 28\%$
1952	5,234	6,039	11,273	$\frac{11,273}{8,620} = 31\%$

TURNER TURNPIKE, OKLAHOMA

Traffic Counter #10-A near Chandler

A.D.T.—1949 = 3,156
 " —1950 = 3,510
 " —1951 = 3,285
 " —1952 = 4,326

} 38% Increase for 3 years
 (Flood)

Turnpike opened May 16, 1953

Traffic increasing at average rate of 12 percent per year from 1949 to 1952.

Expected
 A.D.T.—1953 = 4,326 × 1.12 = 4,840

Actual Average
 on Total Length
 of Turnpike
 3,550

Yearly A.D.T.	Traffic Counts			Percent Induction in Corridor
	Turnpike	Counter #10-A U.S. 66	Total	
1953	3,550	3,400	6,950	$\frac{6,950}{4,840} = 44\%$

NEW HAMPSHIRE TURNPIKE
Annual Average Daily Traffic

<u>Year</u>	<u>U. S. r</u>	<u>New Hampshire Turnpike</u>	<u>Total Both Routes</u>
1943	3,897		
1944	4,017		
1945	4,583		
1946	6,749		
1947	6,841		
1948	7,990		
1949	8,851		
1950*	6,346	7,516 ¹	
1951	4,897	6,999	11,896
1952	5,341	7,618	12,959
1953	5,725	8,088	13,813

* Turnpike opened June 24, 1950.

¹ Average daily traffic, June 24-December 31, 1950.

SOURCE: New Hampshire Department of Public Works and Highways.

EFFECT OF NEW HAMPSHIRE TURNPIKE ON CORRIDOR TRAFFIC

Total Traffic for Month

<u>Month</u>	<u>Year</u>	<u>U. S. r</u>	<u>New Hampshire Turnpike</u>	<u>Total Both Routes</u>	<u>Difference</u>
July	1948	397,110	Not Opened	397,110	
July	1949	439,205	Not Opened	439,205	42,095
(Turnpike opened June, 1950)					
July	1950	204,843	298,554	503,397	64,192
July	1951	224,040	337,126	561,166	57,769
July	1952	256,493	366,595	623,088	61,922
July	1953	272,900	393,024	665,924	42,836
July	1954	279,815	442,347	722,162	56,238

SOURCE: New Hampshire Department of Public Works and Highways.

III. TOLL ROAD TRIP LENGTHS

TRIP LENGTH, NEW YORK STATE THRUWAY

<i>Date</i>	<i>Length Open to Traffic (miles)</i>	<i>Average Trip Length</i>			<i>Composite Average (miles)</i>
		<i>Cash Passenger (miles)</i>	<i>Permit Passenger (miles)</i>	<i>Commercial (miles)</i>	
June, 1954	115	42	25	55	41
July	115	47	28	58	45
August	115	51	31	61	48
September	172	57	37	73	55
October	183	59	40	77	56
November	366	65	46	80	62
December	366	64	42	81	61
January, 1955	381	60	43	84	58
February	381	59	44	86	58
March	381	61	45	86	58
April	381	72	49	86	67
May	381	72	49	84	67
June	395	70	47	83	66
July	395	76	49	83	72
August	395	69	46	81	66
September	395	67	41	70	63
October	395	68	48	83	65
November	395	64	48	83	62
December	424	60	45	83	59

SOURCE: New York State Thruway Authority.

TRIP FREQUENCY, NEW JERSEY TURNPIKE

The following is an array of trip frequency on an average daily basis during 1953 compared to similar figures for 1952.

<i>Trips Between Inter- Changes</i>	<i>Trip Length (miles)</i>	1953			1952		
		<i>Order</i>	<i>No. of Trips</i>	<i>Percent Total Trips</i>	<i>Order</i>	<i>No. of Trips</i>	<i>Percent Total Trips</i>
14-18	13.5	1	3,871	6.4	2	2,721	5.5
14-16	9.0	2	3,586	5.9	3	2,497	5.0
1-18	118.7	3	3,347	5.5	1	3,043	6.1
17-18	4.4	4	3,097	5.1	5	2,080	4.2
11-14	14.0	5	2,596	4.3	4	2,230	4.5
11-18	27.5	6	2,580	4.3	6	2,078	4.2
11-16	23.0	7	2,358	3.9	7	2,000	4.0
15-18	9.9	8	2,294	3.8	9	1,611	3.2
15-16	5.4	9	2,223	3.7	10	1,610	3.2
1-16	114.2	10	1,841	3.0	8	1,661	3.3
4-18	84.3	11	1,640	2.7	11	1,464	3.0
11-15	17.6	12	1,481	2.4	12	1,226	2.5
4-16	79.8	13	1,194	2.0	14	1,073	2.2
11-17	23.1	14	1,129	1.9	17	851	1.7
1-14	105.2	15	1,110	1.8	13	1,201	2.4
9-18	35.5	16	1,097	1.8	15	933	1.9
1-3	25.5	17	943	1.6	16	894	1.8
1-4	34.4	18	888	1.5	18	742	1.5
9-16	31.0	19	875	1.4	19	742	1.5
11-13	8.9	20	847	1.4	24	637	1.3
13-18	18.6	21	843	1.4	23	682	1.4
12-13	4.4	22	820	1.4	27	521	1.0
1-15	108.8	23	742	1.2	21	695	1.4
1-7	53.3	24	741	1.2	22	683	1.4
7-18	65.4	25	731	1.2	25	588	1.2
4-14	70.8	26	677	1.1	20	699	1.4
9-14	22.0	27	668	1.1	26	549	1.1
14-17	9.1	28	657	1.1	31	418	0.8
9-10	6.8	29	653	1.1	39	325	0.7
				75.2			73.4

All other trips represent less than one percent of the total traffic.

SUMMARY

<i>Trip Length (miles)</i>	<i>Percent of Trips</i>
Up to 5	6.5
5-10	17.0
10-25	21.4
25-50	10.6
50-100	8.2
100-118.7	11.5 (5.5 percent through trips)

NOTE: This distribution includes only those trips listed in the above tabulation.

SOURCE: New Jersey Turnpike Authority.

IV. BRIDGES

RATE OF TRAFFIC GROWTH ON TOLL BRIDGES AND TUNNELS

The following are examples of traffic increases for the five years 1947-1951, inclusive (immediate post-war years).

	<i>Percent</i>
Chain of Rocks, St. Louis, Mo.	64
Vicksburg, Miss., Bridge	56
Bankhead Tunnel, Mobile, Ala.	44
Potomac River Bridge, near Dahlgren, Va. (George Washington Memorial)	162
Delaware River Ferry, Pennsville to New Castle	77
Susquehanna River Bridge, near Havre de Grace, Md.	97
Pennsylvania Turnpike (1946-50 only)*	81
Philadelphia-Camden Bridge	50
Holland Tunnel, New York	28
Lincoln Tunnel, New York	82
George Washington Bridge, New York	90
Henry Hudson Bridge, New York	63
Bronx-Whitestone Bridge, New York	130
Triborough Bridge, New York	138
Queens-Midtown Tunnel, New York	72
Charter Oak Bridge, Hartford, Conn.	213

* The eastern extension was completed in October 1950 and for that reason the figures for 1951 are not comparable.

SOURCE: *Traffic Estimates for Expressways and Other Public Toll Revenue Projects*, George W. Burpee. *Traffic Quarterly*, January, 1953.

INDUCED TRAFFIC ON NEW TOLL BRIDGES AND TUNNELS

(Additional traffic through corridor during first year after opening the facility.)

	<i>Percent</i>
San Francisco-Oakland Bay Bridge	64
Golden Gate Bridge	78
Tacoma Narrows Bridge, Washington	81
Philadelphia-Camden Bridge	74
Holland Tunnel	88
George Washington Bridge	65
Brooklyn-Battery Tunnel	75 ±
Delaware River Memorial Bridge, Newcastle (10 months only)	63
Chesapeake Bay Bridge (one month only)	100 ±

SOURCE: (As above).

TRAFFIC VOLUME CHANGES BROUGHT ABOUT BY BRIDGE CONSTRUCTION

<i>Name of Bridge</i>	<i>Year Opened</i>	<i>Traffic for Year After Bridge Opening</i>			<i>Estimate Assuming No Bridge (A.D.T.)</i>	<i>Percent Total Traffic Increase</i>	<i>Percent Induced Traffic</i>
		<i>Bridge (A.D.T.)</i>	<i>Ferry (A.D.T.)</i>	<i>Total (A.D.T.)</i>			
<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	<i>(8)</i>
Oakland Bay	1936	26,816	1,115	27,931	13,890	101 ¹	64 ¹
First Tacoma Narrows	1940	1,348 ²	0	1,348 ²	658	105 ²	62 ²
Second Tacoma Narrows	1950	3,978 ⁴	0	3,978 ⁴	2,059	111 ³	95 ³

¹ Of the total new vehicular volume, consultants estimated 8,900 (64%) was induced, while 5,140 (37%) represented a travel mode change.

² One consultant estimated that a stabilized A.D.T. volume for a full year (the bridge was open only 4 months) would have been 1,348. Of the increase, it was estimated that 62% was induced, 30% was increased travel because of the lowered toll schedule, and 13% represented a diversion from Seattle ferry facilities.

³ Another consultant estimated that a stabilized bridge volume would have been 1,710. Of the increase, it was estimated that 95% was induced and 16% resulted from lowered fares.

⁴ Consultants calculated the induced traffic to be 87%, and estimated that about 6% was made up of diversion from Seattle ferries. Highway Planning Division analysis verifies this conclusion.

SOURCE: Highway Planning Division, Washington State Highway Department.

RECORD OF TRAFFIC
SAN FRANCISCO—OAKLAND BAY BRIDGE

<i>Year</i>	<i>Bus</i>		<i>Train</i>		<i>Motor Vehicle</i>	
	<i>Passengers</i>	<i>Revenue</i>	<i>Passengers</i>	<i>Revenue</i>	<i>Vehicles</i>	<i>Revenue</i>
1945	8,457,035	\$211,426	26,469,118	\$631,215	22,128,039	\$6,270,105
1946	9,352,723	233,818	22,177,212	387,538	25,353,875	7,314,510
1947	8,218,082	205,452	17,015,228	297,626	25,877,837	7,675,501
1948	7,736,024	193,401	15,630,648	273,550	26,210,503	7,772,918
1949	6,829,789	170,745	13,868,116	242,689	27,339,680	8,087,069
1950	6,479,338	161,983	11,811,795	206,573	28,906,652	8,609,519
1951	7,241,372	181,034	10,254,986	179,178	30,185,286	9,044,286
1952	6,735,545	168,389	9,757,468	170,392	30,882,854	9,305,340
1953*	4,609,251	115,231	6,604,790	115,327	31,638,109	9,545,656

The above figures do not include toll-free passage.

* No rail and bus passengers carried 7/24/53 to 10/7/53 due to strike of Key System employees.

TOTAL REVENUE, 1936-1953

Bus and Rail (Jan. 15, 1939-Dec. 31, 1953)	\$ 7,882,562
Motor Vehicle (Nov. 12, 1936-Dec. 31, 1953)	115,598,054
	\$123,480,616

Source: California Department of Public Works.

EFFECT OF REPLACING A TOLL FERRY BY A TOLL BRIDGE

GEORGE P. COLEMAN BRIDGE

Gloucester, Virginia

Bridge opened to traffic May 1, 1952. Traffic previously served by Gloucester Point -Yorktown Ferry.

<i>Period of Traffic Count (Ferry)</i>	<i>Number Vehicles Using Ferry</i>	<i>Annual Increase</i>
May 1, 1950–April 31, 1951	516,905	
May 1, 1951–April 31, 1952	621,728	20.3%
<i>Period of Traffic Count (Bridge)</i>	<i>Number Vehicles Using Bridge</i>	<i>Annual Increase</i>
May 1, 1952–April 31, 1953	951,764	53.2%
May 1, 1953–April 31, 1954	1,016,488	6.8
	<i>Ferry</i>	<i>Bridge</i>
Time to cross (including waiting time)	15 min.	3 min.
Toll Rates:		
Passenger car (one way)	\$0.55	\$0.75
Passenger car (round trip)	0.80	—
" Commutation ticket	—	0.50
Trucks	1.00 to	1.00 to
	2.00	3.00
Buses	1.00 to	2.00 to
	2.00	3.50
Extra passengers and pedestrians	0.15 ea.	Free
Average charge per vehicle	0.73	0.73

There are no competing facilities.

A toll bridge on Route 17 (James River Bridge) has been in operation a number of years. Volumes using this bridge follow:

<i>Period of Operation</i>	<i>Number Vehicles Using Bridge</i>	<i>Annual Increase</i>
May 1, 1950–April 31, 1951	881,846	
May 1, 1951–April 31, 1952	1,063,237	20.2%
May 1, 1952–April 31, 1953	1,172,476	10.2
May 1, 1953–April 31, 1954	1,275,959	8.8

By comparison of the Coleman Bridge with the James River Bridge, it appears that 10.2% of the increase for the first year of operation would have occurred without changing the type of facility. Therefore the induced traffic was apparently a 43% increase in the first year of operation.

SOURCE: Virginia Department of Highways.

CHESAPEAKE BAY BRIDGE

Maryland

Bridge opened to traffic July 30, 1952. Traffic previously served by Sandy Point-Matapeake Ferry.

<i>Period of Count</i>	<i>Average Daily Traffic Count</i>	
	<i>Ferry</i>	<i>Bridge</i>
1949	1,970	
1950	2,226	
1951	2,494	
1952	2,615 (7 months)	5,286 (5 months)
1953		5,295
1954		5,493 (7 months)
	<i>Ferry</i>	<i>Bridge</i>
Time to cross	30 min.	6 min.
Average waiting time	14 min.	—
Toll Rates:		
Passenger car and driver	\$1.40	\$1.40
Additional passengers	0.25	0.25
Trucks	Vary	Vary

SOURCE: Maryland State Roads Commission.

SANDY POINT—MATAPEAKE FERRY, CHESAPEAKE BAY BRIDGE

Maryland

YEAR	1950			1951			1952			1953		
MONTH	Volume	A.D.T.	Percent Chge.	Volume	A.D.T.	Percent Chge.	Volume	A.D.T.	Percent Chge.	<i>Volume</i>	<i>A.D.T.</i>	<i>Percent Chge.</i>
January	44,153	1,425	+14	48,524	1,565	+10	50,657	1,634	+4	101,827	3,284	+101
February	40,484	1,446	+17	43,382	1,549	+7	55,911	1,928	+24	105,675	3,777	+96
March	45,584	1,470	+4	59,297	1,913	+31	58,731	1,894	-1	122,692	3,958	+109
April	58,303	1,943	+15	63,655	2,122	+9	69,905	2,330	+10	144,755	4,825	+107
May	68,098	2,196	+9	74,767	2,411	+10	84,444	2,724	+13	163,090	5,261	+93
June	84,805	2,827	+19	95,920	3,197	+13	108,625	3,621	+13	199,884	6,663	+84
July	103,553	3,340	+9	116,899	3,770	+13	*135,993	4,787	+27	253,526	8,178	+86
August	105,331	3,511	+15	121,502	4,050	+15	276,267	8,912	+127	268,062	8,647	-3
September	79,939	2,665	+11	91,844	3,061	+15	147,304	4,910	+60	176,976	5,899	+20
October	66,928	2,159	+12	73,856	2,382	+10	145,614	4,697	+97	150,381	4,851	+3
November	58,870	1,962	+13	64,005	2,134	+9	124,077	4,136	+93	124,569	4,152	+0
December	54,211	1,749	+6	56,575	1,825	+4	112,854	3,640	+99	121,304	3,913	+8
TOTAL	810,259	2,226	+12	910,226	2,494	+12	1,370,382	3,744	+51	1,932,741	5,295	+41

* The Sandy Point-Matapeake Ferry ceased operations at close of July 30, 1952, with the opening of the Chesapeake Bay Toll Bridge. 9,966 vehicles crossed the bridge on July 31.

SOURCE: Maryland State Roads Commission.

NUMBER OF TRIPS BY LENGTH OF TRIP
USING CHESAPEAKE BAY FERRY OR CHESAPEAKE BAY BRIDGE

TRIP MILEAGES	FERRY — 1952		BRIDGE — 1952			BRIDGE — 1953		
	Number	Percent	Number	Percent	Bridge	Number	Percent	Bridge
					Ferry			Ferry
Under 25	25	0.8	149	2.2	+496%	123	2.0	+ 392%
25-50	308	9.6	887	13.0	+188	719	11.9	+ 133
50-100	1,124	34.9	1,858	27.2	+ 65	1,571	26.0	+ 40
100-150	996	31.0	1,818	26.7	+ 83	1,603	26.6	+ 61
150-200	442	13.7	876	12.9	+ 98	794	13.2	+ 80
200-250	93	2.9	289	4.2	+211	264	4.4	+ 184
250-300	38	1.2	99	1.5	+161	74	1.2	+ 95
300-350	28	0.8	123	1.8	+339	44	0.7	+ 57
350-400	3	0.1	16	0.2	+433	33	0.6	+1000
400 and over	160	5.0	702	10.3	+339	810	13.4	+ 406
TOTAL	3,217	100.0	6,817	100.0	+112	6,035	100.0	+ 88

SOURCE: Maryland State Roads Commission.

**EFFECT OF CHANGE FROM FERRY TO TOLL BRIDGE
AND TOLL BRIDGE TO FREE BRIDGE**

CAIRO, ILLINOIS BRIDGE OVER THE OHIO RIVER

		<i>A.A.D.T.</i>	<i>1948 Bridge Tolls (One Way)</i>
1936	Ferry	120	Car including passengers \$.75
1938	Toll Bridge	400	Motorcycle .25
1941	" "	825	Trucks .75 to 5.00
1947	" "	1,550	Semitrailers 2.50 to 4.00
1950	Free Bridge	2,850	Full trailers 2.50 to 4.00
1953	" "	5,800	House trailers .50
			Buses 1.00 to 1.25
			Horse-drawn vehicles .75

HUTSONVILLE, ILLINOIS BRIDGE OVER THE WABASH RIVER

		<i>A.A.D.T.</i>	<i>1950 Bridge Tolls (One Way)</i>
1938	Ferry	30	Car including passengers \$.25 and .50
1941	Toll Bridge	140	Motorcycles .10
1947	" "	300	Trucks .50 and .75
1950	" "	450	Semitrailers .75
1953	" "	550	

**QUINCY, ILLINOIS BRIDGE
OVER MISSISSIPPI RIVER**

**HANNIBAL, MISSOURI BRIDGE
OVER MISSISSIPPI RIVER**

(20 miles south of Quincy Bridge)

		<i>A.A.D.T.</i>		<i>A.A.D.T.</i>
1936	Toll	1,420	Toll	780
1938	"	1,300	"	800
1941	"	1,000	Free (1941)	1,700
1947	Free (1945)	2,850	"	2,200
1950	"	4,700	"	3,200
1953	"	6,500	"	3,300

SOURCE: Illinois Department of Public Works and Buildings.

TRAFFIC COUNTS MADE ON BRIDGES BEFORE AND AFTER THEY WERE FREED OF TOLLS

West Virginia

Year of Count	Huntington-Chesapeake			Chelyan			Satties			"Shadle" (Henderson)			"Silver" (Pt. Pleasant)			Mason-Pomeroy		
	P.	C.	A.A.D.T.	P.	C.	A.A.D.T.	P.	C.	A.A.D.T.	P.	C.	A.A.D.T.	P.	C.	A.A.D.T.	P.	C.	A.A.D.T.
1940	2,900	463	3,363	—	—	—	293	44	337	500	175	675	435	182	617	241	85	326
1941	3,576	828	4,404	285	104	389	389	49	438	—	—	—	—	—	—	273	96	369
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1945	3,178	808	3,986	324	145	469	782	46	828	906	319	1,225	—	—	—	488	306	794
1946	4,476	860	5,336	814	286	1,100	1,374	322	1,696	1,350	474	1,824	826	305	1,131	861	302	1,163
1947	4,828	828	5,656	—	—	—	2,290	390	2,680	1,417	498	1,915	895	315	1,210	1,304	474	1,178
1948	5,701	931	6,632	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1949	6,312	976	7,288	—	—	—	3,154	778	3,932	—	—	—	—	—	—	—	—	—
1950	6,707	1,001	7,708	—	—	—	—	—	—	2,244	788	3,032	—	—	—	—	—	—
1951	7,022	1,002	8,024	—	—	—	5,264	945	6,200	2,301	809	3,110	—	—	—	2,701	949	3,650
1952	8,674	3,016	11,690	3,112	1,093	4,205	6,476	1,163	7,639	2,790	980	3,770	3,080	1,082	4,162	—	—	—
1953	9,492	3,058	12,550	—	—	—	6,955	1,249	8,204	—	—	—	—	—	—	—	—	—
Date Freed	6-7-52			8-7-46			2-7-46			7-4-45			12-3-46			10-30-46		

TOLL SCHEDULES IN EFFECT BEFORE BRIDGES WERE MADE TOLL FREE

Autos	.25	.25	.25	.25-.35 ¹	.25-.35 ¹	.25-.35 ¹
Extra passengers	.05	.05	no charge	.05	.05	.05
Taxis	.15	← Same fare as for Auto →				
Motorcycles	.10	—	.10	.10-.15	.10-.15	—
Trucks	.10-.75	.25-.55	.25-.35	.40-1.40	.35-2.70	.25-.75
Semi-trailers	.50-1.00	.75-.95	.35-1.15	.40-2.40	.35-2.70	—
Full trailers	.50-1.00	—	.95	.40-2.40	.35-2.70	—
House trailers	.25	—	.10	.20	.20	—
Buses	.50-.75	—	.25-.55	.50	.50	—
Horse-drawn veh.	.25	—	.10-.20	.20	.20	—

¹.25 for coupes. All bridges listed have two lanes.

<i>Year of Count</i>	Hurricane Deck Bridge (Intrastate) Camden County, Missouri Route 5 north of Camdenton	Fairfax Bridge (Interstate) Platte County, Missouri Routes 69 and 169 Kansas City
	<i>A.A.D.T.</i>	<i>A.A.D.T.</i>
1948	112	2,151
1949	104	3,514
1950	229	8,556†
1951	213	9,460
1952	242	11,143
1953	550*	12,536
1954	605	13,986
1955	587	12,984

* Made toll-free March 18, 1953. January-March A.D.T. = 381.

† Made toll-free March 7, 1950.

TOLL SCHEDULES IN EFFECT BEFORE BRIDGES WERE MADE
TOLL FREE

Auto	\$.65	\$.25
Extra passenger	.05	no charge
Motorcycle	.25	.10
Truck	1.00-1.25	.25-.40
Semi-trailers	.75-1.00	.40
Buses	.75	.40

SOURCE: Missouri State Highway Commission.

GENERAL SULLIVAN BRIDGE, DOVER-NEWINGTON
New Hampshire

<i>Year of Count</i>	<i>A.A.D.T.</i>	<i>Year of Count</i>	<i>A.A.D.T.</i>
1935	1,987	1945	2,435
1936	2,147	1946	3,365
1937	2,280	1947	3,603
1938	2,231	1948	3,873
1939	2,338	1949	4,304*
1940	2,322	1950	5,318
1941	3,105	1951	6,100
1942	2,435	1952	6,860
1943	1,944	1953	7,110
1944	2,229	1954	7,733

* Bridge tolls removed November 1, 1949.

TOLL SCHEDULE IN EFFECT BEFORE BRIDGE WAS MADE

TOLL FREE

Automobile	\$.15
Automobile—15-trip ticket	1.00
Automobile with trailer	2 auto trip tickets or .25
Truck or automobile in public service, charging a per capita fare	.25
50-trip ticket	10.00
Truck registered for 1,000 pounds or less	Same as automobile
Truck with trailer, or any 3-axle vehicle	.35
30-trip ticket	9.00
Motorcycle	.05
Pedestrian or bicycle and rider	.03
Vehicle drawn by one horse	.10
Vehicle drawn by two or more horses	.15
Horse and rider	.10
Cattle, horses, sheep or swine on foot	.05

SOURCE: New Hampshire Department of Public Works and Highways.

EFFECT OF NEW TOLL BRIDGE ON TRAFFIC GENERATION

AND DIVERSION

ST. LOUIS METROPOLITAN AREA BRIDGES

(Average Daily Traffic)

Date	Douglas McArthur Bridge*	McKinley Bridge	Eads Bridge†	Jefferson Barracks Bridge	Chain of Rocks Bridge	Veterans Memorial Bridge	Corridor Totals
1948	18,684	8,420	15,569	1,789	3,765	—	48,227
1949	21,388	8,924	17,016	2,212	4,026	(Opened	53,566
1950	24,224	9,490	18,544	2,774	4,422	January, 1951)	59,454
1951	19,870	8,777	15,408	3,086	4,838	15,919	67,808
1952	19,776	8,686	16,043	3,469	4,950	18,974	71,898
1953	19,886	8,920	17,188	3,728	6,282	21,713	77,717

* 1.2 miles south of Veterans Memorial.

† 0.15 miles south of Veterans Memorial.

TOLL RATES

Auto and driver	.10	.20	.20	.25	.25	.10
Addit. pass.	—	.05	.05	.05	.05	—
Motorcycle	.10	.10	.15	.25	.20	—
Truck (min.)	.25	.50	.35	.40	.40	.25
Semitrailer (min.)	.25	.50	.60	.55	.40	.35
Bus (min.)	.25	.50	.50	.50	.40	.50

SOURCE: Missouri State Highway Commission and Illinois Department of Public Works and Buildings.

V. STATUS OF TOLL ROADS

STATUS ON TOLL ROADS, AS OF MARCH 1, 1956

State	Name of Road or Location ¹	Year Built or Estimated Completion Date	Mileage				Actual or Estimated Cost (\$1,000 Dollars) ⁴	
			Completed	Under Construction or Financed	Authorized ²	Proposed ³		Total
Colorado	Denver-Boulder Turnpike	1952	17.3	—	—	—	17.3	\$6,237
Connecticut	Connecticut Turnpike (Greenwich-Killingly) ⁵	1957	—	129.0	—	—	129.0	398,000
	Merritt Parkway ⁶	1940	37.5	—	—	—	37.5	720,592
	Wilbur Cross Parkway ⁶	1949	29.5	—	—	—	29.5	17,500
	Windsor Locks-Enfield	—	—	—	3.0	—	3.0	7,000
	Subtotal, Connecticut		67.0	129.0	3.0	—	199.0	443,092
Florida	Buccaneer Trail ¹	1950	17.5	—	—	—	17.5	4,600
	Sunshine State Parkway (Miami area-Fort Pierce)	1957	—	110.0	—	—	110.0	74,000
	Fort Pierce-Jacksonville area	—	—	—	276.6	—	276.6	185,000
	Cross-State spur to Tampa	—	—	—	64.0	—	64.0	40,000
	Subtotal, Florida		17.5	110.0	340.6	—	468.1	303,600
Georgia	Brunswick-St. Simon Causeway ¹	1924	11.1	—	—	—	11.1	3,150
Idaho	Lewis and Clark Highway ¹	—	—	—	—	22.0	22.0	35,000
Illinois	Chicago-Rockford-Beloit	1957	—	88.4	—	—	88.4	150,677
	Chicago Belt Line (Hammond, Indiana-Wisconsin line)	1959	—	80.2	—	—	80.2	222,344
	Maywood-Aurora	1957	—	24.7	—	—	24.7	41,979
	Aurora-Rock Island area	—	—	—	128.1	—	128.1	140,000
	St. Louis-Cincinnati Turnpike (Illinois section)	—	—	—	—	154.0	154.0	163,000
	Subtotal, Illinois		—	193.3	128.1	154.0	475.4	718,000
Indiana	East-West Turnpike (Ohio line-Illinois line)	1956	—	156.0	—	—	156.0	280,000
	North-South Turnpike (Gary area-Indianapolis area)	—	—	—	131.0	—	131.0	178,000
	St. Louis-Cincinnati Turnpike (Indiana section)	—	—	—	—	160.0	160.0	200,000
	Indianapolis-Cincinnati	—	—	—	—	110.0	110.0	100,000
	Subtotal, Indiana		—	156.0	131.0	270.0	557.0	758,000
Iowa	Davenport-Council Bluffs	—	—	—	—	297.7	297.7	180,000
Kansas	Turnpike (Kansas City via Topeka & Wichita to Oklahoma line)	1957	—	236.0	—	—	236.0	160,000
	Turnpike extension: Bonner Springs-Missouri line	—	—	—	—	56.0	56.0	33,220
	Subtotal, Kansas		—	236.0	—	56.0	292.0	193,220
Kentucky	Turnpike (Louisville-Elizabethtown)	1956	—	40.0	—	—	40.0	38,500
Louisiana	Lafayette-Lutcher	—	—	—	86.0	—	86.0	100,000
	Laplace-New Orleans	—	—	—	24.6	—	24.6	20,000
	Subtotal, Louisiana		—	—	110.6	—	110.6	120,000
Maine	Turnpike (Kittery-Portland)	1947	47.2	—	—	—	47.2	20,600
	Portland-Augusta extension	1955	66.0	—	—	—	66.0	55,000
	Augusta-Fort Kent extension	—	—	—	279.0	—	279.0	195,000
	Subtotal, Maine		113.2	—	279.0	—	392.2	270,600
Maryland	Northeastern Expressway (Baltimore-Elkton area)	—	—	—	48.0	—	48.0	29,526
Massachusetts	Turnpike (New York line-Boston area)	1956	—	123.0	—	—	123.0	239,000
	Turnpike extension into Boston	—	—	—	14.0	—	14.0	85,000
	Subtotal, Massachusetts		—	123.0	14.0	—	137.0	324,000
Michigan	Rockwood-Saginaw	—	—	—	113.0	—	113.0	194,000
	Extensions to Ohio line and Straits of Mackinac	—	—	—	—	217.0	217.0	191,000
	Ypsilanti-Gary	—	—	—	170.0	—	170.0	215,000
	Subtotal, Michigan		—	—	283.0	217.0	500.0	600,000

¹ Facilities indicated by "1" are principally resort or seasonal roads, not serving through traffic. Omitted from this tabulation are the Jacksonville, Florida, toll expressway system, the Calumet Skyway in Chicago, Illinois, and the proposed Loveland Pass tunnel in Colorado which are not classified as toll roads.

² Legislation has been enacted authorizing or permitting (if found feasible) construction of these toll roads. Financing arrangements have not been completed. Omitted are authorized projects in Florida and Oklahoma for which mileage and cost data are not available.

³ Includes toll roads recommended for study as to feasibility by State Governors, highway departments, turnpike officials, or legislative committees. As of current date, plans and locations have not been firmly established. Cost and mileage data are therefore only approximate. Omitted are a) projects discussed informally, b) those proposed at a previous time, but apparently not now receiving serious consideration, c) projects studied and found presently infeasible, including those for which enabling legislation has been introduced but failed of enactment.

⁴ "Actual" costs refer in most instances to proceeds of bond issues and hence include interest during construction.

⁵ The State is required to pay maintenance and collection costs, and in addition, pay the debt service to the extent that toll receipts and the bond reserve fund are not adequate to meet the full debt service requirements.

⁶ The Connecticut and Westchester County (N.Y.) parkways were not built as self-liquidating, limited-access toll roads. Commercial vehicles are denied use of the parkways.

⁷ Includes Federal grant of approximately \$400,000 from Public Works Administration.

⁸ Includes toll-free sections in vicinity of urban areas.

⁹ This includes 17.5 miles of connecting links built by the State Highway Department on which tolls will not be charged. Costs are included. Trucks are prohibited on the 75-mile section of the Parkway north of Lakewood.

¹⁰ The proceeds of these bond issues include the pro-rata share borne by the Pennsylvania Turnpike Commission and the New Jersey Turnpike Authority of the bridge across the Delaware (to be opened in 1956) linking these toll roads.

¹¹ 1953 legislature authorized a 10-cent toll on the existing Southern State Parkway to help finance a \$40-million parkway construction and improvement program. Toll collections began in July, 1954.

¹² The Ohio Turnpike Commission has modified its plans for this project by eliminating the spur to Toledo and a 45-mile section of the main route (in the central part of the State) where State highways will be used. The above mileage and cost data reflect these changes.

¹³ Includes \$29,250,000 Federal grant from the Public Works Administration.

¹⁴ Cost of completed mileage includes 17 miles of New Hampshire Central (Everett) Turnpike and 3 miles of New York Thruway now under construction. A segregation of costs is not available.

¹⁵ Cost of mileage under construction includes 37 miles of Pennsylvania Turnpike's Northeastern Extension (Philadelphia-Scranton section) now open to traffic. A segregation of costs is not available.

STATUS ON TOLL ROADS, AS OF MARCH 1, 1956

State	Name of Road or Location ¹	Year Built or Estimated Completion Date	Mileage				Actual or Estimated Cost (1,000 Dollars) ⁴	
			Completed	Under Construction or Financed	Authorized ²	Proposed ³		Total
New Hampshire	Turnpike (Seabrook-Portsmouth)	1950	14.7	—	—	—	14.7	6,770
	Central (Everett) Turnpike ⁸	1956	21.6	17.1	—	—	38.7	22,400
	Portsmouth-Rochester extension (Spaulding Turnpike) ⁸	1957	—	22.8	—	—	22.8	14,300
	Subtotal, New Hampshire		36.3	39.9	—	—	76.2	43,470
New Jersey	Garden State Parkway ⁹	1955	165.0	—	—	—	165.0	330,000
	Extension to New York Thruway		—	—	9.5	—	9.5	18,000
	New Jersey Turnpike (Delaware River to George Washington Bridge interchange)	1952	117.6	—	—	—	117.6	318,952
	Turnpike extensions:							
	Newark Airport interchange-Holland Tunnel	1956	—	8.1	—	—	8.1	120,048
	Bordentown interchange-Pennsylvania Turnpike extension	1956	—	6.0	—	—	6.0	¹⁰ 27,200
	Newark-Columbia Extension to New York Thruway		—	—	59.0	—	59.0	300,000
Delaware River Bridge (Camden)-Atlantic City		—	—	15.0	—	15.0	60,000	
	Subtotal, New Jersey		282.6	14.1	83.5	47.0	427.2	1,256,700
New York	New York Thruway System:							
	Buffalo-New York City section	1956	424.0	3.0	—	—	427.0	675,428
	Niagara section	1957	—	21.8	—	—	21.8	
	Erie section	1956	—	70.6	—	—	70.6	321,938
	New England section	1956	—	15.1	—	—	15.1	
	Berkshire section		—	—	24.0	—	24.0	62,332
	Garden State Parkway connection		—	—	2.5	—	2.5	4,300
	New Jersey Turnpike connection		—	—	5.9	—	5.9	10,980
	Long Island Expressway (Mineola-Riverhead)		—	—	52.0	—	52.0	93,800
	Westchester County Parkways: ⁶							
	Saw Mill River Parkway (toll portion)	1926	11.1	—	—	—	11.1	3,500
	Hutchinson River Parkway (toll portion)	1927	11.2	—	—	—	11.2	4,600
	Cross County Parkway	1940	4.0	—	—	—	4.0	1,800
	Long Island Parkways:							
Southern State Parkway ¹¹	1956	17.5	5.5	—	—	23.0	40,000	
Meadowbrook, Loop and Wantagh Causeways ¹	1934	13.4	—	—	—	13.4	5,050	
Captree Parkway (toll portion) ¹	1954	4.2	—	—	—	4.2	11,000	
	Subtotal, New York		485.4	116.0	84.4	—	685.8	1,234,728
Ohio	Turnpike (Pennsylvania line-Indiana line)	1955	241.4	—	—	—	241.4	326,000
	Cincinnati-Conneaut ¹²		—	—	262.0	—	262.0	380,000
	St. Louis-Cincinnati Turnpike (Ohio section)		—	—	—	22.0	22.0	22,000
	Subtotal, Ohio		241.4	—	262.0	22.0	525.4	728,000
Oklahoma	Turner Turnpike (Oklahoma City-Tulsa)	1953	88.0	—	—	—	88.0	38,585
	Turnpike extensions:							
	Tulsa-Missouri line	1957	—	88.5	—	—	88.5	68,000
	Oklahoma City-Kansas line		—	—	97.6	—	97.6	63,000
	Oklahoma City-Texas line (near Wichita Falls)		—	—	134.0	—	134.0	83,000
Oklahoma City-Tulsa to Texas line near Gainesville		—	—	193.0	—	193.0	149,000	
	Subtotal, Oklahoma		88.0	88.5	424.6	—	601.1	401,585
Pennsylvania	Turnpike (Irwin-Carlisle)	1940	158.9	—	—	—	158.9	¹³ 77,164
	Eastern extension (Carlisle-Valley Forge)	1950	100.9	—	—	—	100.9	87,000
	Western extension (Irwin-Ohio line)	1951	67.4	—	—	—	67.4	77,500
	Delaware River extension (Valley Forge-Delaware River)	1954	32.3	—	—	—	32.3	¹⁰ 80,120
	Northeastern extension (Philadelphia-Scranton)	1956	37.2	73.1	—	—	110.3	217,880
	Northeastern extension (Scranton-Sayre)		—	—	40.0	—	40.0	40,000
	Northeastern extension (lateral spurs)		—	—	104.0	—	104.0	170,000
	Gettysburg extension (to Maryland line)		—	—	33.0	—	33.0	33,000
	Northwestern extension (New York line-Ohio line via Erie)		—	—	46.0	—	46.0	62,000
	Southwestern extension (Pittsburgh to West Virginia line)		—	—	50.0	—	50.0	100,000
	Keystone Shortway (Stroudsburg-Sharon)		—	—	360.0	—	360.0	630,000
Pocono Mountain Memorial Parkway ¹		—	—	69.0	—	69.0	22,500	
	Subtotal, Pennsylvania		396.7	73.1	702.0	—	1,171.8	1,597,164
Rhode Island	Connecticut line-Massachusetts line		—	—	40.0	—	40.0	50,000
Texas	Dallas-Fort Worth Turnpike	1957	—	30.5	—	—	30.5	\$58,500
	Dallas-Fort Worth area to Houston via Waco		—	—	250.0	—	250.0	140,000
	Houston-Corpus Christi		—	—	170.0	—	170.0	104,000
	Dallas-Fort Worth area-Oklahoma line		—	—	65.0	—	65.0	40,000
	Houston to Port Arthur via Beaumont		—	—	—	80.0	80.0	49,000
	Subtotal, Texas		—	30.5	485.0	80.0	595.5	391,500
Virginia	Richmond-Petersburg	1958	—	34.7	—	—	34.7	69,000
Washington	Tacoma-Seattle-Everett		—	—	65.2	—	65.2	227,000
West Virginia	Turnpike (Charleston-Princeton)	1954	87.6	—	—	—	87.6	133,000
	Turnpike extensions:							
	Charleston to Pennsylvania & Ohio lines (via Fairplain)		—	—	—	225.0	225.0	338,000
	Subtotal, West Virginia		87.6	—	—	225.0	312.6	471,000
Total Mileage			1,844.1	1,384.1	3,484.0	1,390.7	8,102.9	
Total Actual or Estimated Cost			¹⁴ \$2,340,328	¹⁵ \$2,527,586	\$4,231,438	\$1,393,720	—	\$10,493,072

APPENDIX B

CRITICAL HOUR TRAFFIC DATA

Table 1

30TH HIGHEST HOUR VOLUMES IN CONNECTICUT

(As a percent of the Annual Average Daily Traffic)

Route or Street	Town or City	Suburban Routes—Both Directions					
		1940	1947	1950	1951	1952	1953
Conn. 32	Montville	13.5	11.6	12.0	12.1	—	11.7
U.S. 5	East Windsor	16.6	14.6	13.8	13.2	12.7	12.7
Conn. 12	Killingly	14.2	12.2	12.8	11.5	11.9	12.0
U.S. 6	West Hartford	12.9	11.2	11.9	11.3	11.1	10.6
Conn. 34	Orange	13.0	12.6	12.6	12.5	13.1	—
Charter Oak	Hartford	—	—	—	—	—	10.7
River Front Blvd.	Hartford	—	15.1	15.6	12.9	13.1	10.9
Weighted Average		13.7	13.3	13.9	12.4	12.7	10.9
		Urban Residential Streets					
		1940	1947	1950	1951	1952	1953
Bushnell St.	Hartford	—	11.8	11.8	12.9	12.9	11.9
Enfield St.	Hartford	—	11.5	11.4	11.0	10.4	10.3
Weighted Average		—	11.7	11.6	12.2	11.7	11.1
		Urban Through Streets					
		1940	1947	1950	1951	1952	1953
U.S. 1	Westport	7.8	8.1	7.5	6.9	7.3	6.9
Albany Ave.	Hartford	—	8.6	8.8	9.2	9.6	8.2
Main St.	Hartford	—	8.1	7.8	7.8	8.7	7.6
New Britain Ave.	Hartford	—	10.2	9.1	9.1	9.6	9.8
Weighted Average		7.8	8.6	8.2	8.1	8.8	8.0

SOURCE: Connecticut State Highway Department.

Table 2
DIRECTIONAL DISTRIBUTION OF TRAFFIC
DURING 30TH HIGHEST HOUR IN CONNECTICUT

Location	Percent in Dominant Direction					
	1940	1947	1950	1951	1952	1953
<i>Partial Recreational Routes</i>						
Rt. 82, Conn. R. Bridge, East Haddam	68	56	50	51	52	57
Rt. 156, Niantic R. Bridge, Waterford	59	63	57	57	58	55
Rt. U.S. 1, Baldwin Bridge, Old Lyme- Old Saybrook	—	—	68	67	68	63
<i>Parkways</i>						
Merritt Parkway, Greenwich	62	62	59	58	58	57
Wilbur Cross Parkway, Milford	—	56	56	58	55	56
Wilbur Cross Parkway, Wallingford	—	—	—	—	55	55
<i>Suburban Routes</i>						
Rt. 5A, Riverfront Blvd., Hartford	—	67	77	83	72	79
Rt. U.S. 1, Washington Br., Milford	57	60	58	56	57	64
Rt. U.S. 5 and 15, Charter Oak Br., Hartford	—	—	—	—	—	54
<i>Urban Routes</i>						
Main Street, Hartford	—	59	56	58	62	59
Rt. U.S. 1, Stratford Ave., Bridgeport	59	54	56	53	55	53
Rt. U.S. 1, Tomlinson Br., New Haven	—	57	57	58	63	58
Rt. U.S. 1, Mystic R. Br., Groton- Stonington	51	51	50	51	52	56
Rt. 136, Norwalk R. Br., Norwalk	—	—	54	55	54	52

SOURCE: Connecticut State Highway Department.

Table 3
PEAK HOUR VOLUMES IN URBAN AREAS IN MARYLAND
AS A PERCENTAGE OF 24-HOUR VOLUMES

City	Year	No. of Streets	Morning Peak		Evening Peak	
			Total Volume	Percent	Total Volume	Percent
Baltimore	1946	9	10,372	7	11,633	8
Hagerstown	1947	18	2,446	3	3,595	5
Frederick	1948	18	2,891	6	4,145	9
Cumberland	1949	12	3,861	6	5,033	8
Salisbury	1949	10	4,189	4	5,031	7
Annapolis	1950	9	2,966	6	4,195	9
Total		76	26,725	6	33,632	8

Table 4

DIRECTIONAL DISTRIBUTION OF TRAFFIC DURING PEAK HOURS
IN MARYLAND, 1952

<i>Location</i>	<i>Dominant Flow, in Percent</i>	
	<i>A.M. Peak</i>	<i>P.M. Peak</i>
Rt. Md. 2, Ritchie Hwy., South of Glen Burnie	72	65
Rt. U.S. 140, Reistertown Rd., at Druid Ridge Cemetery	70	68
Rt. U.S. 40, Pulaski Hwy., at Belcamp	65	64
Rt. Md. 151, North Point Rd., at Matthai Avenue	60	82
Rt. Md. 150, Eastern Ave., at Sewer Road	59	59

SOURCE: Maryland State Roads Commission.

ATLANTA, GEORGIA

A 24-hour cordon count made in Atlanta, Georgia, in 1953 at from one and a half to two miles from the city center on 29 streets leading downtown showed the morning peak to be $7\frac{1}{2}$ percent of the 24-hour total, and the evening peak to be 9 percent of the 24-hour total. Traffic counts further showed two-thirds of the total flow during the P.M. peak hour outbound.